PGI/82/WS/17
Paris, November 1982

UNESCO

CONSOLIDATION OF INFORMATION

WINDPUMP HANDBOOK

(Pilot edition)

Prepared by

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General Information Programme and UNISIST

United Nations Educational, Scientific and Cultural Organization

The Unesco Symposium on Information Analysis and Consolidation held in Colombo from 12 to 15 September 1978 recommended the establishment of pilot information consolidation units in selected priority areas and the distribution of their outputs for repackaging and adaptation for various categories of users.

In accordance with this recommendation, the Division of the General Information Programme of Unesco provided assistance to the Tata Energy Research Institute for the establishment of an information consolidation unit and for the preparation of information products consisting of evaluated, analyzed and consolidated information in three selected fields: biogas, windmills and cooking stoves.

At the end of Phase I of the Work Plan for 1980/81 agreed between Unesco and the Tata Energy Research Institute, the following pilot editions had been produced:

1. Biogas Handbook
2. Windpump Handbook
3. Cooking stoves Handbook
4. Review of the Literature on Promotion of Windpumps
5. Review of the Literature on Promotion of Biogas Systems

Phase II of the project involves the improvement of these pilot editions, their distribution and testing in the field, repackaging of the information for application by users at various levels and an evaluation of the results of the entire project at the end of 1983. In this context the opinions of the readers of these documents will be very useful. Comments should be addressed to:

Division of the General Information Programme
Unesco
75007 Paris

INTRODUCTION

Windmills are becoming an attractive proposition for agricultural pumping in the developing countries. Several units of windmills are currently being fabricated and field tested with a view to establishing their technical feasibility and economic viability. The research and development efforts are about to show results with visible signs of possible commercialisation in the near future. This handbook is intended as a compendium of different types of windmills which could be manufcatured using locally available materials and skills. Information on design features such as rotor assembly, sail or blades, power transmission, tower structure, tail assembly etc., are included along with suitable illustrations. In all, the handbook contains information on 30 different basic types of windmills. Detailed design drawings and other technical specifications are likely to be available free of charge from the designers or the contact addresses mentioned in the text. It is hoped that the present pilot version of the wind pump handbook could be reviewed and evaluated by persons who have responsibilities or interest in consolidating information and that could be subsequently improved and disseminated to a wider audience of specialists, particularly in the developing countries. The Handbook was compiled by Miss T. Rastogi of the Tata Energy Research Institute, Bombay House, 24 Homi Mody Street, Bombay 400 023, India under the supervision of Mr N.K. Gopalakrishnan, Director of the Documentation Centre of the Tata Energy Research Institute. It was then evaluated by Dr. S.K. Tewari, NAL, Bangalore and Dr. R.P. Gupta, BHEL, Hyderabad. Secretarial assistance was rendered by Miss R.H. Marker. The present pilot edition is a photographic reproduction of the author's original manuscript; the opinions expressed are not necessarily those of Unesco or TERI and do not commit the organizations.

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WINDMILLS AND PUMPS

Windmills work on the principle of converting kinetic energy of the wind to mechanical energy. The main component of a windmill is the rotor assembly which consists of sails or metal blades attached to spokes radiating outward from a hub. The hub is mounted on a shaft which is capable of rotating on bearings. The pressure of the wind makes the sail or blade assembly turn on its axis and this rotation of the shaft can be used for operating a pump etc. The power developed is directly proportional to the area swept by the blades and the cube of the wind velocity.

Horizontal axis windmills have their rotors oriented normal to the wind direction (Fig. 1)

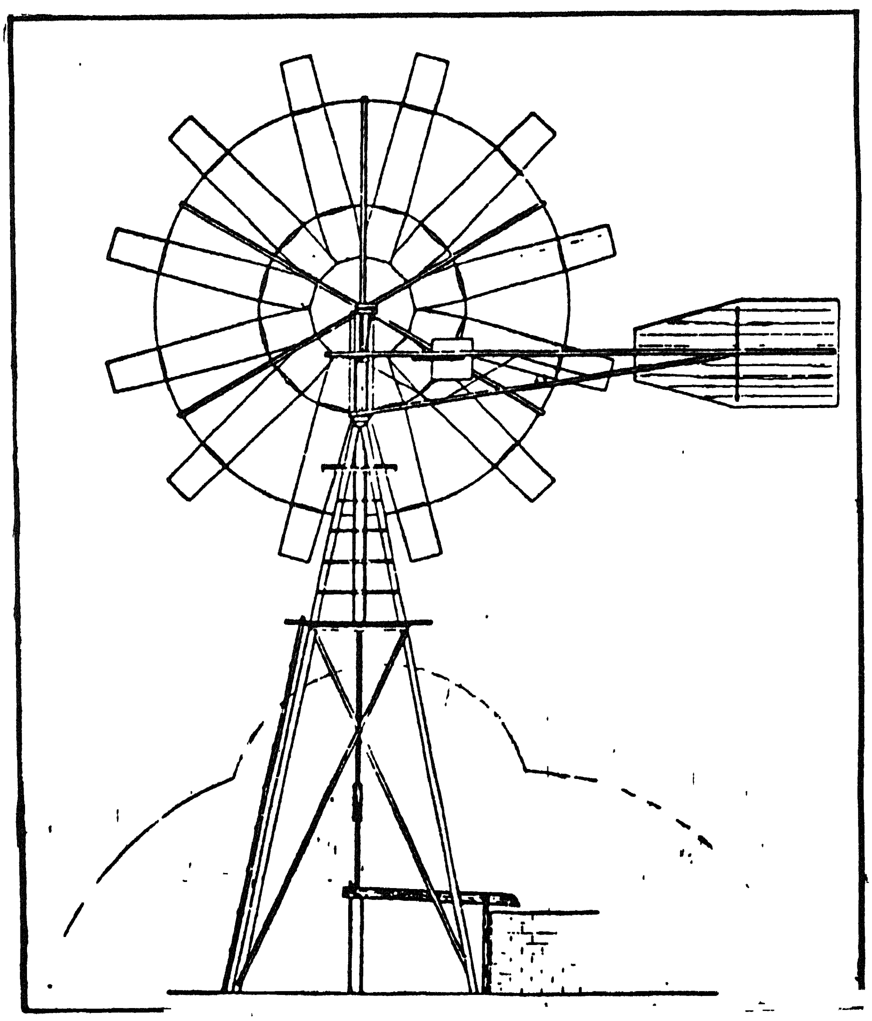


Fig. 1: Horizontal-axis Windmill

The shaft power is transmitted to the pump in several ways. If a reciprocating pump is used, rotary motion of the shaft is converted to reciprocating motion either by an eccentric wheel mounted on the shaft (see Anila-1) or a crank mechanism (see CAZRI design). If a rotary pump is used, an endless belt connects a pulley mounted on the windmill shaft to a pulley on the pump shaft. Bevel gears (see NAL design) can also be used to transmit power in such cases. Windmills designed for multidirectional winds have a vane attached to the turntable (as in Fig. 1). This vane intercepts the changing wind direction and orients the rotor to face the wind. Horizontal axis windmills having a large number of blades or sails have a high starting torque and are ideally suited to water pumping applications. However, their design is complicated because the mechanical energy is transmitted over a distance and secondly, they need to be mounted on a turntable or the like for orienting them to changing wind directions.

Vertical Axis Windmills

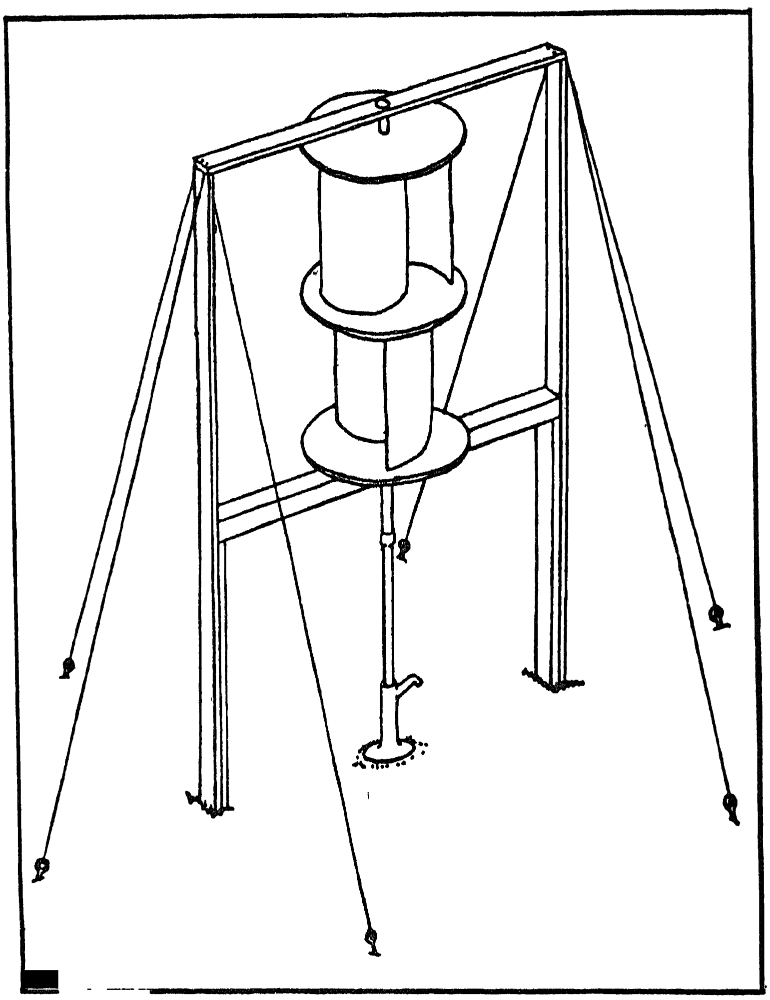


Fig. 2: Vertical-axis Windmill

Vertical axis windmills have their rotors moving in the same direction as the wind. Savonius rotors which have found application in water pumping can be described in general as comprising of an oil barrel cut longitudinally into two halves and welded together to form an 'S' shape and rotating about a vertical shaft supported by a thrust bearing (Fig. 2).

If a reciprocating pump is used, a system of pulleys and crank transmit the power (see IRRI design) or the main shaft extension has an end crank connected to a bell crank mechanism which actuates the pump (see IISc. design). If a rotary pump is used, a system of pulleys or bevel gears can transmit the power. Savonius rotors are simple to construct and do not need any mechanism to orient the rotor since it accepts winds from any direction. The supporting structure can be short and hence less expensive. However, their performance is poor compared to horizontal axis windmills.

Wind Data Collection

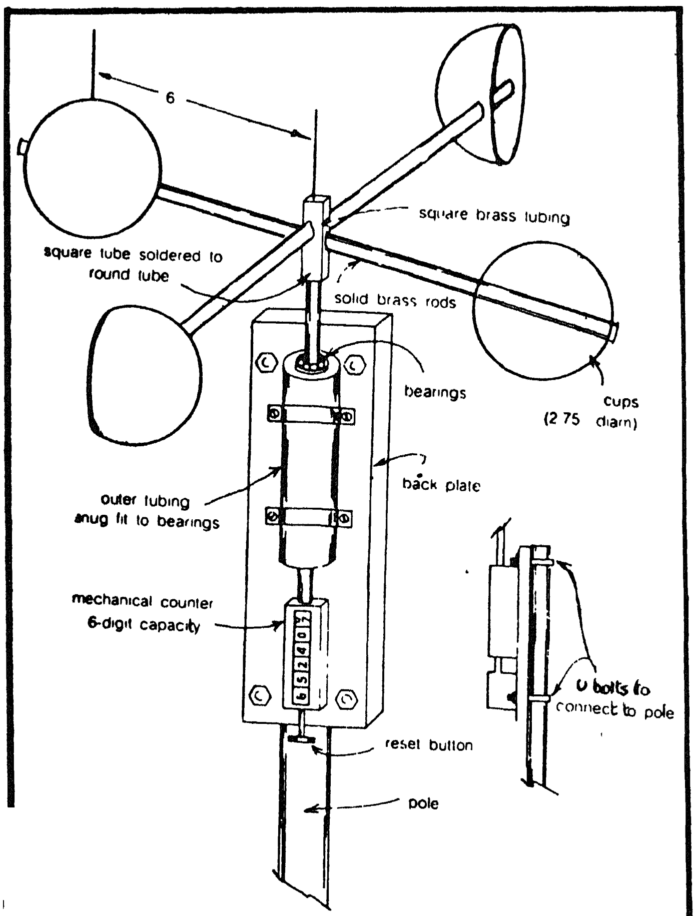
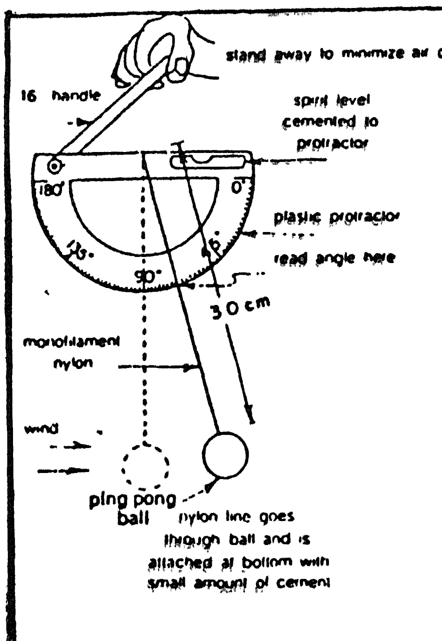


Fig. 3: Cup Anemometer



calibration data

angle	mph
90	0
85	5,8
80	8,2
75	10,1
70	11,8
65	13,4
60	14,9
55	16,4
50	18,0
45	19,6
40	21,4
35	23,4
30	25,8
25	28,7
20	32,5

Fig. 4: A Simple Hand-held Wind Gauge with Calibration Data

Site-specific wind data are essential for wind energy utilization. The hourly mean wind velocity available from a meteorological station is the basic data required. If there is no meteorological station near the site, an anemometer (Fig. 3) can be used to determine the hourly wind velocities. If no anemometer is available, a simple instrument (Fig. 4) is suggested. It uses a protractor, a ping-pong ball (or a similar light-weight ball) suspended by a nylon string. The angle that the string makes when the instrument is held in the wind is a measure of the windspeed. For example if the angle is 50^{o}, the windspeed is 18 mph.

The Beaufort scale given below also helps to give a rough idea of the windspeeds. It matches natural evidences of windspeeds to a measured scale.

Qualitative Description of Windspeed

Windspeed (mph)	(kmph)	m/s	Visible Wind Effects
0-1	0.62	0-.44	Calm: smoke rises vertically.
2-3	.62-5	.44-1.3	Direction of wind shown by smoke drift but not by wind vanes.
4-7	6-11	1.6-3.1	Wind felt on face; leaves rustle; ordinary vane moved by wind.
8-12	12-19	3.9-5.4	Leaves and twigs in constant motion; wind extends light flag.
13-18	20-28	5.7-8.0	Raises dust, loose paper, small branches are moved.
19-24	29-38	8.4-10.6	Small trees in leaf begin to sway, crested wavelets from/on inland waters.
25-31	39-49	12.2-13.6	Large branches in motion; whistling heard in telegraph wires, umbrellas used with difficulty.
32-38	50-61	15.3-16.7	Whole trees in motion; inconvenience felt in walking against wind.

The Beaufort Scale

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Pumps

Water is the most common fluid handled by pumps. Virtually, therefore, all types of pumps may be considered as potentially suitable for water lifting. However, pumps used with wind-powered pumping systems are generally found to be of three types: reciprocating, rotary and diaphragm. Both reciprocating and rotary pumps are of the positive displacement type. A positive displacement type of pump is that in which a measured quantity of water is entrapped in a space, its pressure is raised and then it is delivered.

Reciprocating Pumps

In order to start reciprocating pumps in reasonably low wind-speed, it is necessary to obtain sufficient starting torque which is possibly by using high rotor solidity. Hence many windmills have a large number of vanes or sails to provide high starting torque. All types of reciprocating pumps are selfpriming in that they do not need to be filled with fluid before pumping. The action of reciprocating pumps is illustrated in Fig. 5 and Fig. 6. Fig. 6 shows a pump cylinder. Its diameter and the length of the plunger stroke inside it are major factors in determining the windmill's pumping capacity. The stroke of a windmill is the distance which the plunger moves up and down. A short stroke enables the mill to begin pumping in a light breeze but in strong breeze a long stroke causes more water to be pumped. Fig. 7 shows a plunger-type of reciprocating pump used in a commercial water pumping windmill.

1. Piston Pump

A piston type of pump is normally used for deep bore wells, the pump being located inside the bore pipe directly underneath the windmill and below the water level. Positive displacement-type piston pumps are used to pump water from rivers and lakes commonly used in conjunction with many types of rotors, for pumping from open or tube-wells.

a. Single-acting piston pump

This consists of a cylinder with an inlet pipe and valve at the base, a leather-sealed piston with a one-way valve and a water outlet at the top, water passing through the pump only on the lifting stroke of the piston. These types of pumps are suitable for medium or high heads with an operating speed of up to 40 strokes per minute. This type of pump has been used in the CAZRI Windmill, Lassithiou Windmills, ORP-TOOL Windmill, SWD Cretan Windmill.

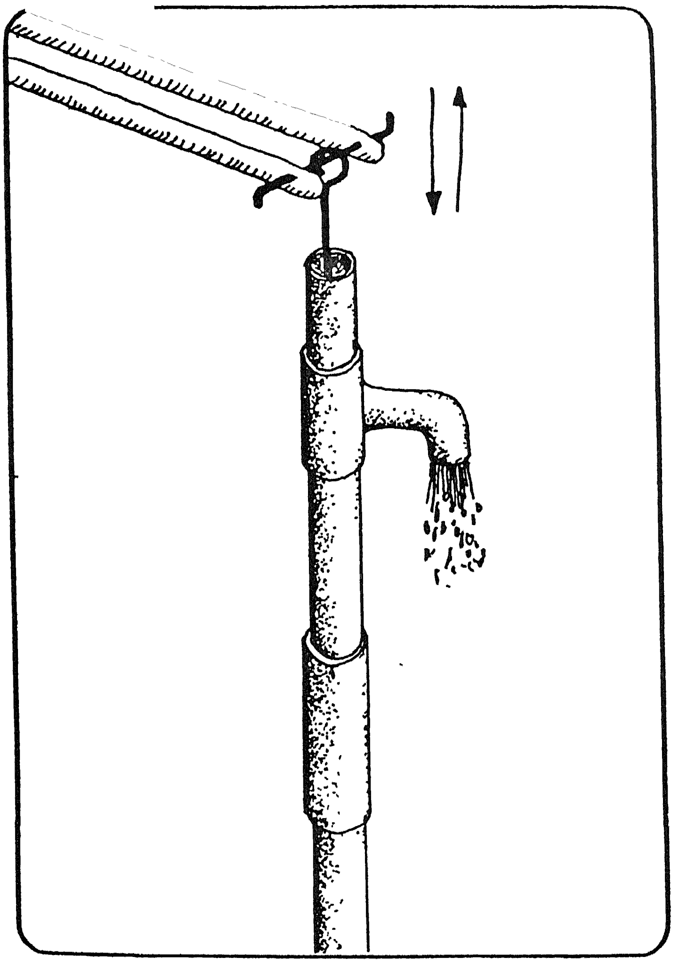


Fig. 5: Reciprocating Piston Pump

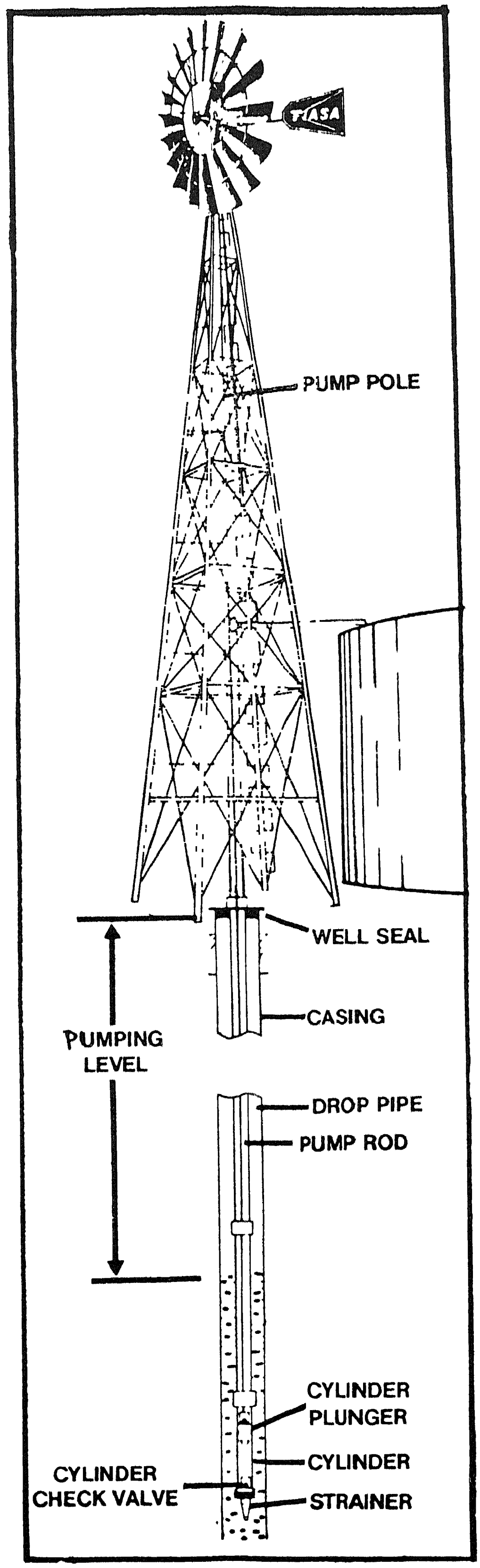


Fig. 7: Pump attached to a Commercial Water Pumping Windmill

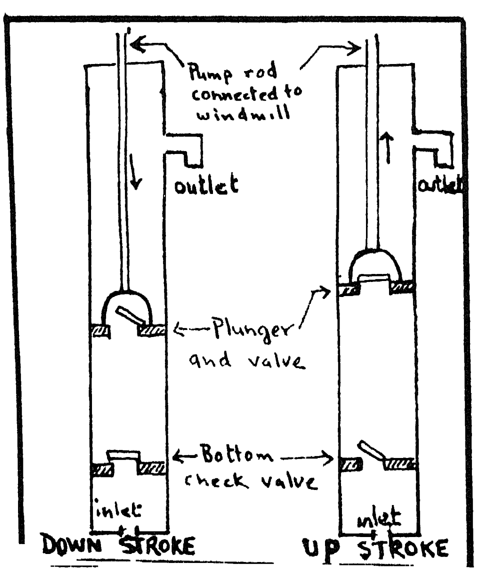


Fig. 6: Pump Cylinder and Valve arrangement

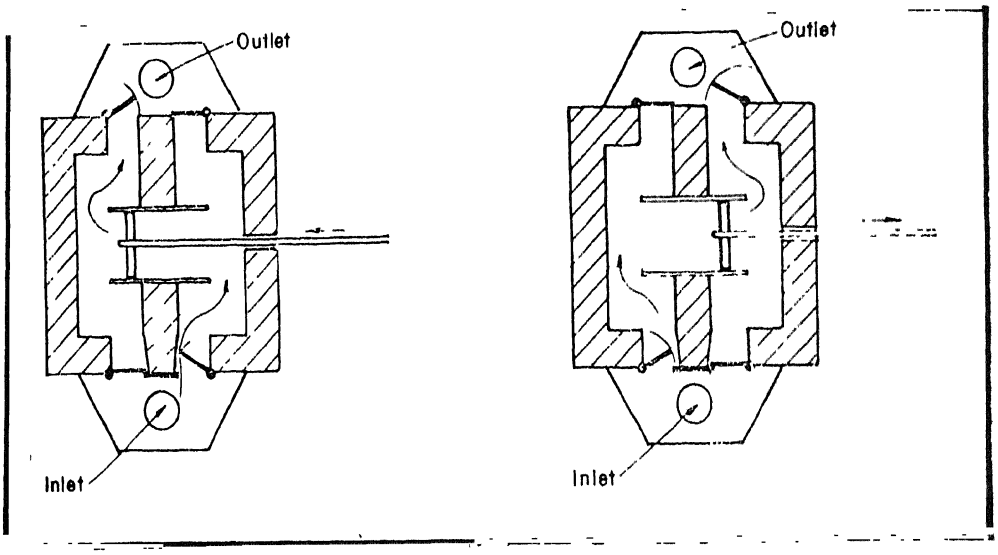


Fig. 8: IRRI Double-acting Piston Pump

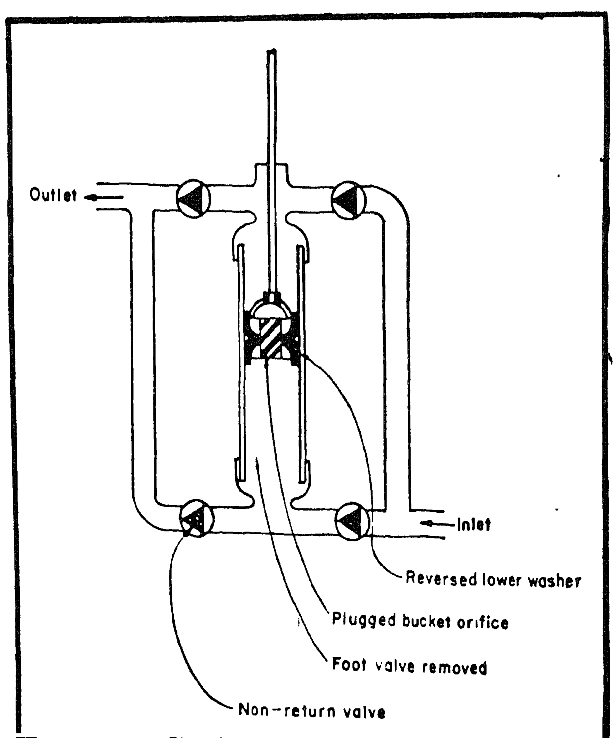


Fig. 9: Double-acting Piston-type Water Pump

This is similar to the single acting pump except that there is no valve or passage of water through the piston, the water by-passing the piston cylinder through pipes and valves under pressure during both upstroke and downstroke. Examples of this type of pump is found in Polomo Windmill, ITDG Wind pump.

2. Diaphragm pump

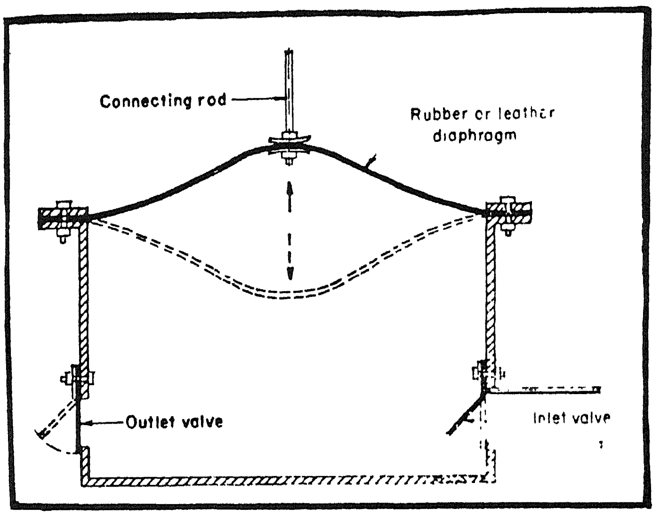


Fig. 10· Diaphragm -type Water Pump

This consists of a cylinder closed at the lower end, with a circular diaphragm of rubber or some other flexible material fixed at the top end. A reciprocating connecting rod is fixed to the centre of the diaphragm and upon vertical movement, causes volumetric displacement in the cylinder. An arrangement of valves allows water movement in only one direction through the cylinder.

Illustrated in Fig. 11 and Fig. 12 is a diaphragm pump. Note the pump rod attachment (Fig. 11) and the pump mounting in Fig. 12.

Diaphragm pumps have been used in NAI Windmill, Brace Research Institute's Savonius Rotor, IISc. Windmill.

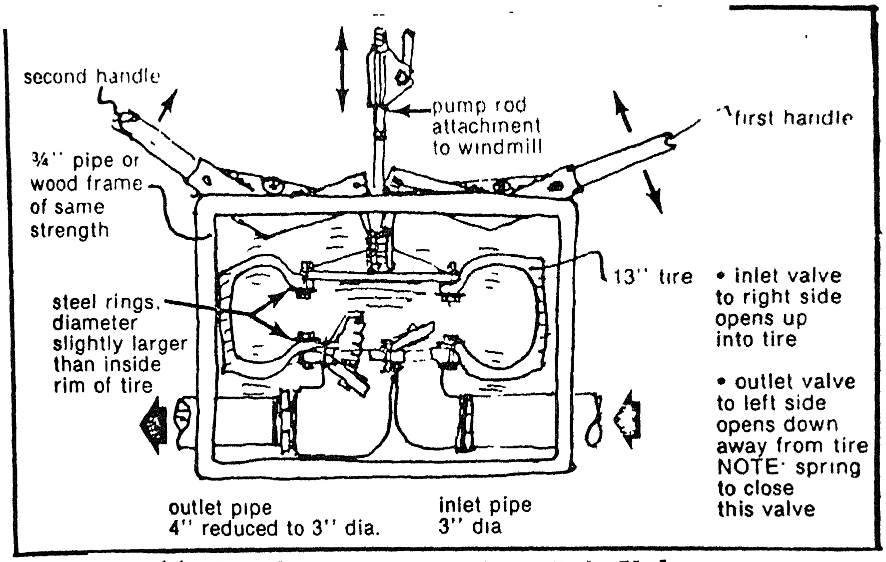


Fig. 11: Diaphragm Pump for High-Volume, Low-lift Irrigation Uses

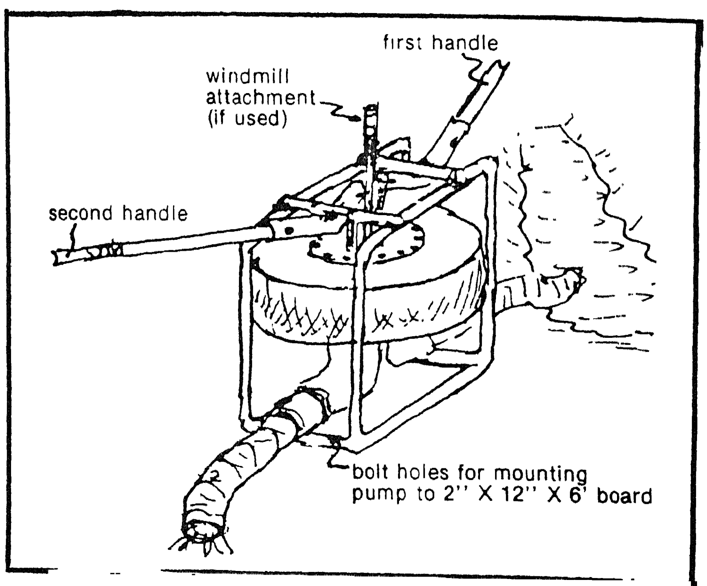


Fig. 12: Diaphragm Pump in Action

3. Rotary pumps

A. Square-wooden pallet chain pump

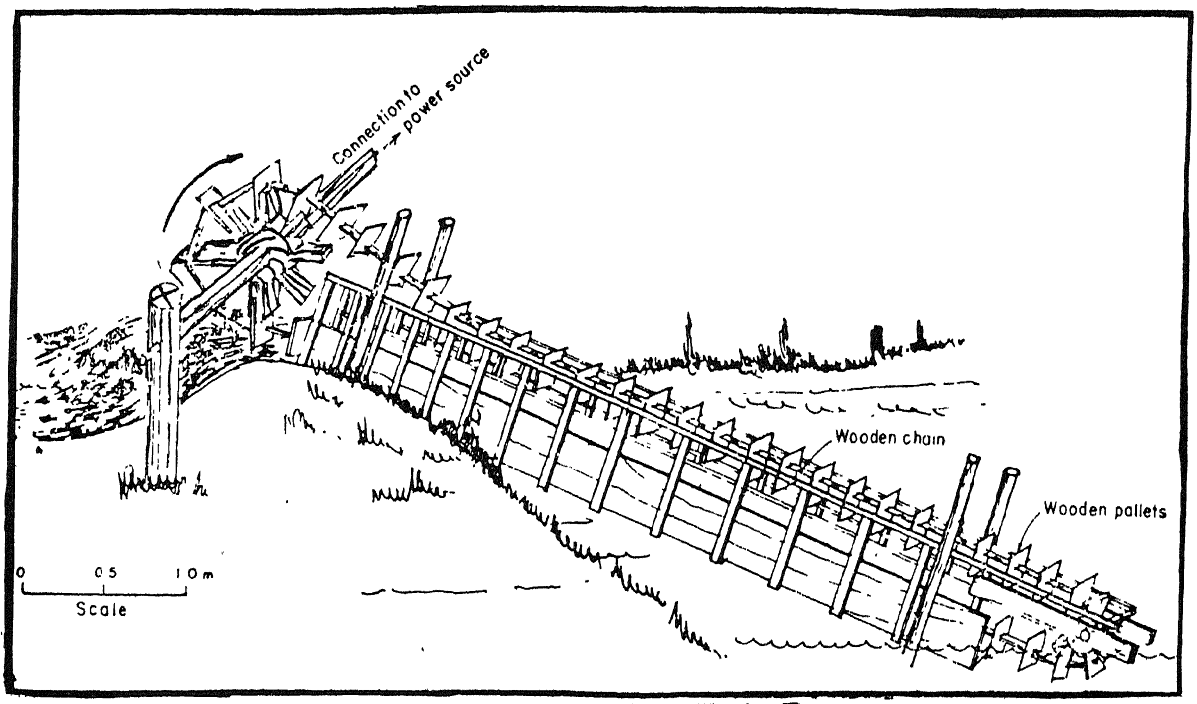


Fig. 13· Square-wooden Pallet Chain Pump

This is commonly used in China and Southeast Asia for a head up to 3 m and consists of rectangular wooden pallets or paddles mounted on a continuous wooden chain that runs up an inclined square section open wooden trough. The paddles and chain pass around a large wooden driving-gear wheel at the top and around a small passive gear wheel, at the base of a trough which is submerged in water. This type of pump is commonly used with Chinese vertical-axis wind pump systems and with Thai high-speed wooden rotors and Thai sail rotors.

Square wooden-pallet chain pumps are often used for high-volume, low-head lifts and are mounted diagonally between adjacent fields or evaporating ponds and small canals.

Example : Thai Bamboo-sail windmills. Thai high-speed rotors.

b. Swinging Vane Rotary Pump

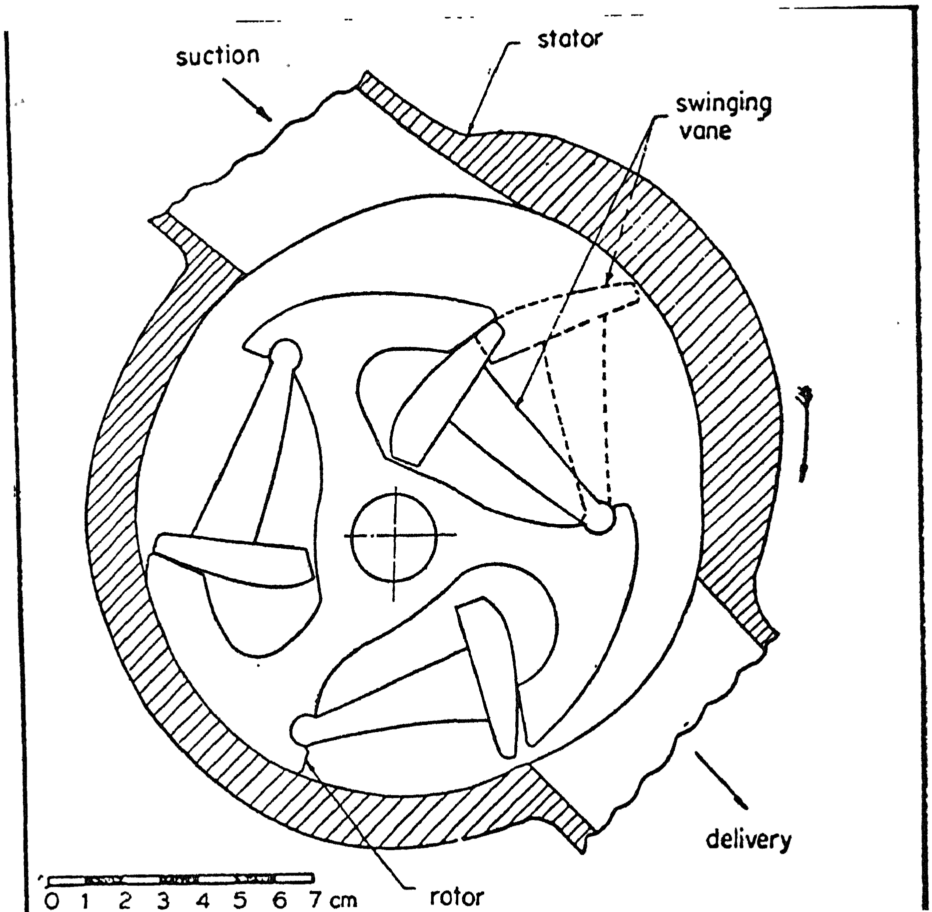


Fig. 14: Swinging-vane Rotary Pump (Schematic) Consisting of Three gun-metal Vanes Pivoted on an Accentrically Mounted Rotor

This type has a rotating member eccentrically located with regard to the casing and is provided with a number of vanes which swing during rotation. Water is trapped between vanes and squeezed out at the discharge side as the eccentricity of the case reduces the space between vanes.

Rotary pumps are self-priming and are capable of operating against a suction head up to 8 m. Swinging vane pumps are suitable for moderate volume, low head and starts operating in low wind-speeds, since they need low starting torque.

Example: NAL Windmill.

Conclusion

For selection by Head and Capacity Fig. 15 (Table) can be of some help. This table can be useful as an initial guide for selecting possible pump types for low or high head requirements at three different capacity levels.

Fig. 15 · Table · Selection by Capacity and Head

Type of Pump	Low Capacity		Medium Capacity		High Capacity	
	Low Head	High Head	Low Head	High Head	Low Head	High Head
Centrifugal, Single-Stage	X	X	X	X	X	
Centrifugal, Two-Stage			X	X	X	X
Centrifugal, Multi-Stage			X	X	X	X
Centrifugal, Self-Priming		X	X	X		
Regenerative, Single-Stage		X	X			
Regenerative, Multi-Stage			X	X		
Mixed Flow					X	X
Axial Flow					X	
Bore Hole Submersible		X		X		X
Bore Hole Immersible		X		X		X
Portable Submersible	X	X	X			
Portable Immersible	X	X	X			
Reciprocating Piston			X	X	X	X
Reciprocating Plunger		X				
Radial Piston				X		
Gear		X	X	X		
Vane	X	X	X			
Screw			X	X	X	X
Diaphragm	X		X			
Peristaltic	X		X			
Flexible Vane	X					
Ejectors			X		X	

X Suitable.

Some performance and construction characteristics of pumps that have been used with water pumping windmills is given in the following table.

Pump type	*Range of head*		*Efficiency (percentage)*	*Starting torque*	*Speed (rev/min)*	*Typical material*
	Suction (m)	*Discharge (m)*				
Piston	7	100	80	high	30	metal
Turbine	5	100	90 max.	low	1,400–2,000	metal
Ladder	0	3	35	medium	80	wood
Wood chain	0	4	50	medium	80	wood
Steel chain	0	30	50	medium	80	metal
Screw	0	5	60	low	30–400	wood
T-pump	7	0	60	low	400	metal
Inertia	0	4		low	80	metal
Piston	10	30	80	high	30	metal
Diaphragm	7	30		high	30	metal, leather
Rope and bucket	0	50	90	high	2	cloth, leather, metal
Double-acting piston	7	100	85	high	30	metal, plastic
Peristaltic	1.5	10	70	low	100	5-12 cm plastic, rubber
Paddlewheel	0	0.5	20	low	80	wood
Persian wheel	0	50	50	medium	4	metal
Spiral wheel	0	1	60	low	60	wood
Propeller	0	7	60	low	400–2,000	metal

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HORIZONTAL AXIS WINDMILLS

ANILA - 1

Designers :

Mr. V. Geethaguru, Research Technologist and
Dr. C.V. Seshadri, Director.

Institutional Affiliation :

Shri AMM Murugappa Chettiar Research
Centre (MCRC),
Photosynthesis & Energy Division,
Tharamani,
Madras 600 042
INDIA.

Background :

Anila-1 was evolved from a simple wind-powered stirrer designed in 1978 for algal ponds. It won the National Research Development Corporation Award in 1979.

Applications :

For nursery irrigation, domestic water supply, shrimp farming, energy forestry, etc.

Type :

Horizontal axis, bidirectional upwind sail-wing device. (See Fig. 16)

Suitability :

For coastal regions with windspeeds in the range of 15-20 kmph.

Design Features :

Rotor Assembly. This comprises of :

- a straight wooden shaft either chiselled out or turned on a lathe, provided with a stub axle at each end

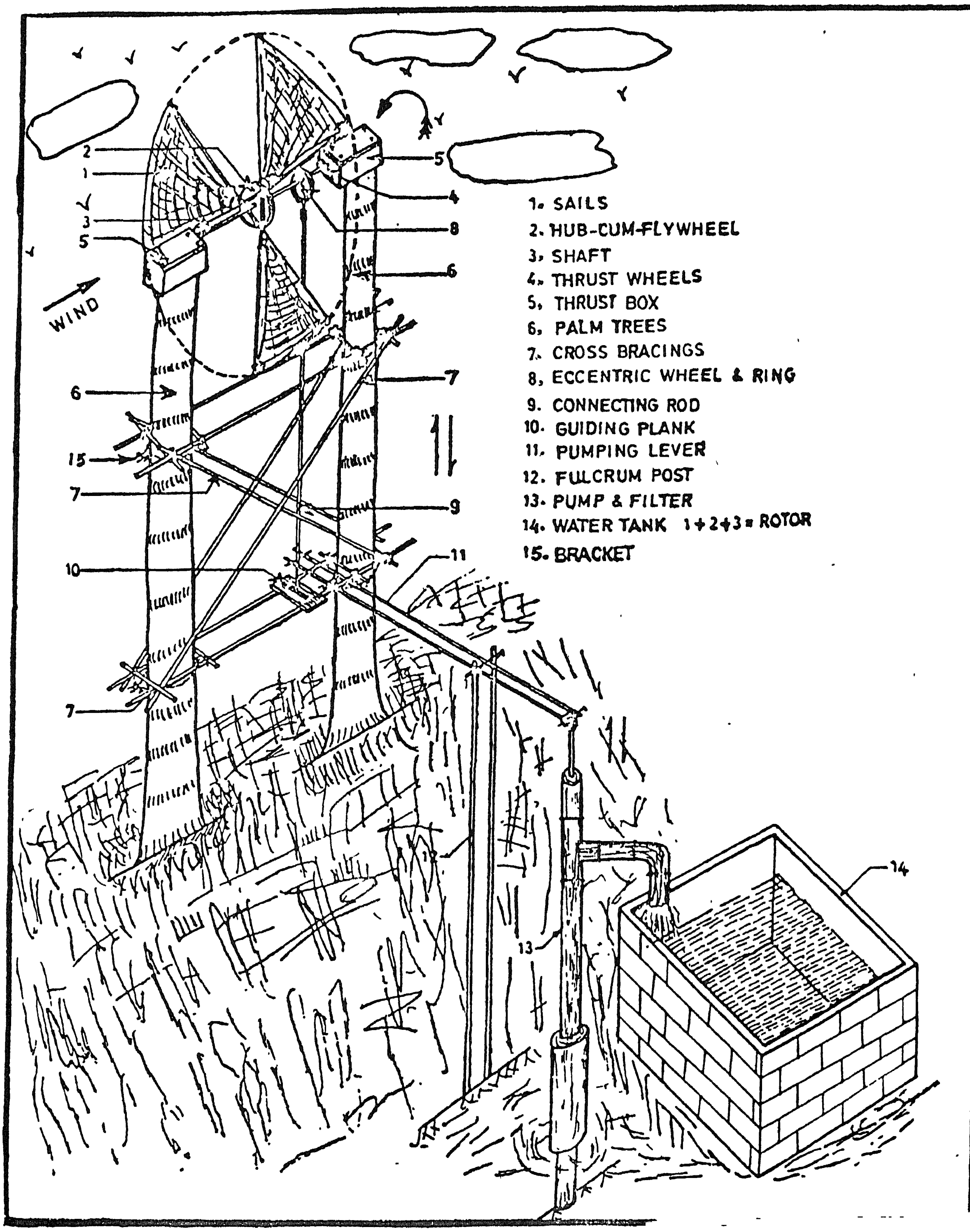


Fig. 16: ANILA 1

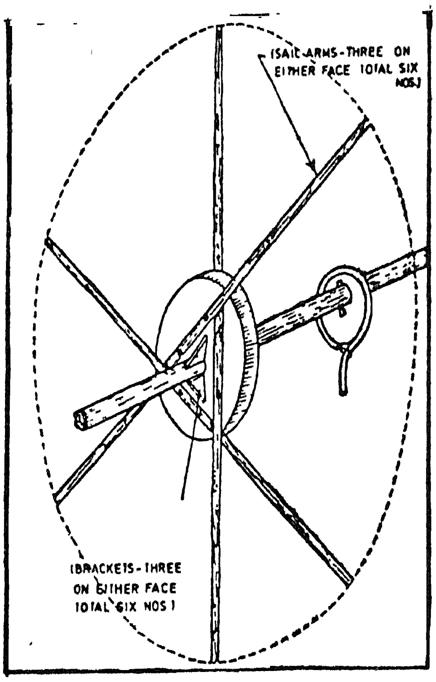


Fig. 17: Rotor Assembly

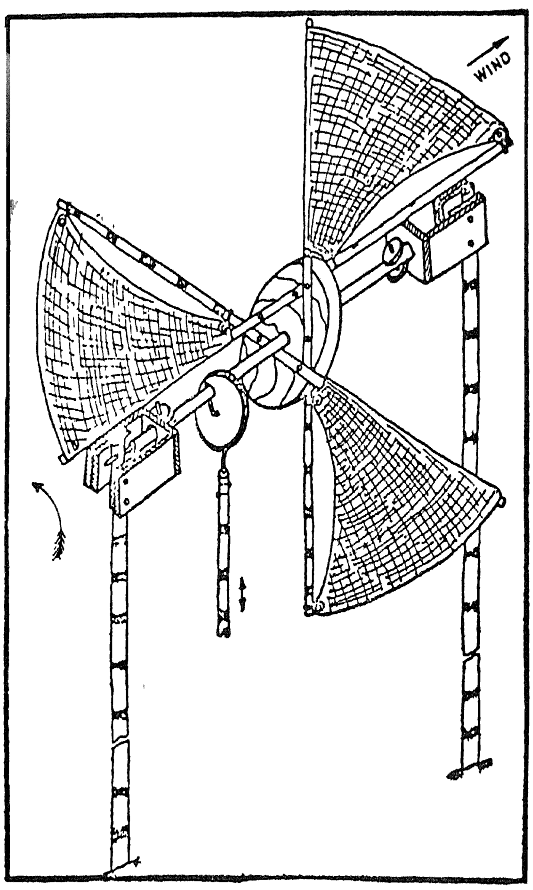


Fig. 18: Rotor and Sail Assembly

- a wooden hub-cum-flywheel secured to the shaft by a key and whose thickness is such that the leading edge and trailing edge of the sails are separated in the wind direction.
- three wooden arms fastened to one another to form an equilateral triangle at the centre (Fig. 17). Two such sets of spokes are placed on either face of the hub and fixed rigidly with screws.

Sails

The sails (3 in number) are triangular and are made of High Density Polyethylene (HDPE) backed by a fish net. They are fixed to the spokes in such a way that the entire length of the sail's leading edge is fastened to the arm whereas only the ends of the trailing edge are hooked up (as shown in Fig. 18) to allow the sail to blow out and adjust aerodynamically, depending on wind velocity and rotor speed.

Power transmission

An eccentric wooden wheel with a suitable circumferential groove is fixed to the shaft. An 'L'-type shear pin transmits the torque from the shaft to the wheel which actuates a connecting rod through an MS ring encircling the wheel along its groove. The connecting rod is attached to a lever moving about a fulcrum. The other end of the lever actuates a reciprocating pump. (Fig. 19)

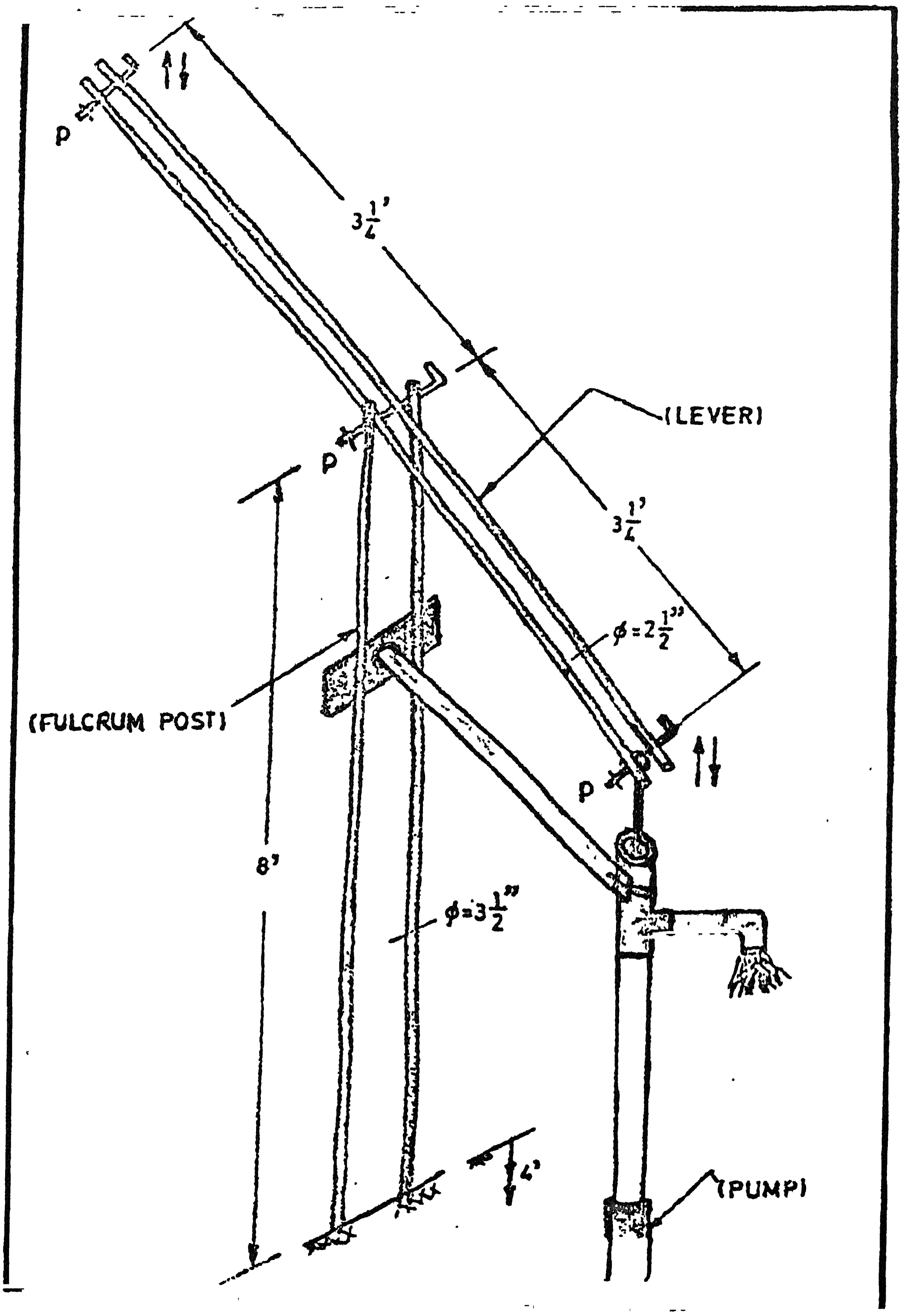


Fig. 19: Fulcrum Post & Lever

Thrust devices

The vertical loading of the shaft is transmitted through the stub axles and the end thrust through a pair of wooden planetary wheels to "thrust boxes" fixed on to the main poles on either end of the shaft.

Pump

A simple piston pump is used with a pump stroke of 229 mm. It consists of a cylinder with a T-joint at the top for water delivery. At the bottom of the cylinder is a fitter 50 mm (2") in diameter and 914 mm (3') in height. A check-value enables only upward flow of water. The position of the check-value, height of the pump above and below ground level are illustrated in Fig. 20.

Tower Structure

The shaft with the rotor is held horizontally at a suitable height by means of casuarina or teak poles or alternatively by palm trees with separate wooden blocks inserted at the top as bearings. The stub axles roll in the augured holes of the top of the poles.

Installation

The windmill should be erected to face the predominant wind direction. However, the rotor is effective even when there is wide variation in wind direction-up to 45^{o} on either side of the shaft line. When the wind direction reverses, the sails have to be rearranged by interchanging the leading and trailing arms thus making the rotor 'alive' again.

Braking

A wooden plain wheel attached to the shaft of the rotor (as the brake-drum with a wooden ridder on it) acts as the braking mechanism. Alternatively a nylon rope tied across the structure may be slid up to bring the rotor to a halt.

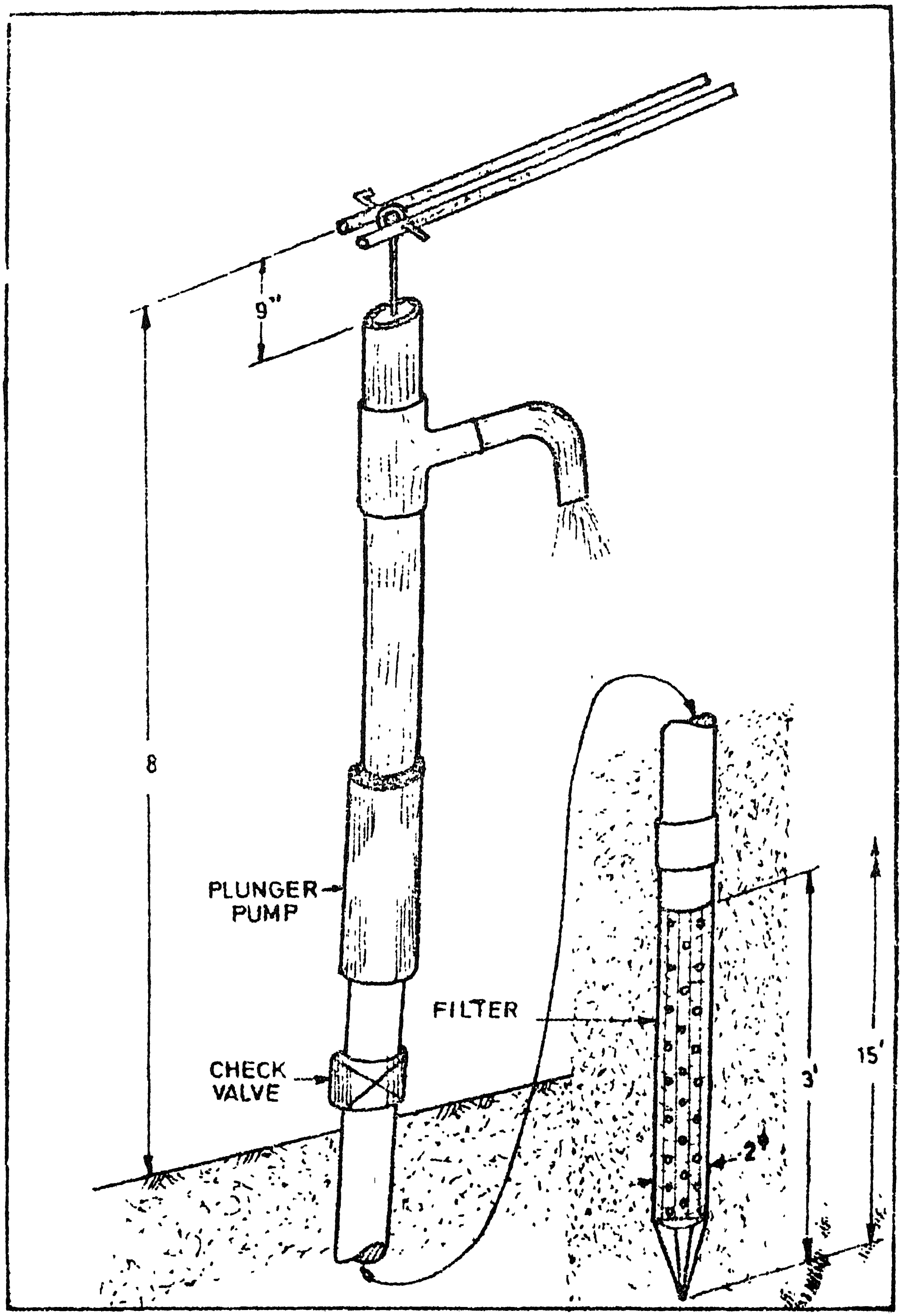


Fig. 20 Plunger-Type Piston Pump

Technical data

Rotor diameter	366 cms
Solidity ratio	31.3
Tip-speed ratio	1.5 to 2
Cut-in windspeed	10 km/hr
Rated windspeed	20 km/hr
Pump diameter	5 cms
Pump stroke	15.25 cms
Pumping head	8 metres
Discharge	1750 lph @ 20 kmph windspeed

Conclusions

The windmill can be made by village-level artisans using materials normally found in villages and it does not incorporate any ball bearings.

Several units are reported to have been commissioned so far. The design know how (patent applied for) is available free of charge to interested users. Engineering drawings and fabrication details could be obtained from the designers.

References

1. Anila windmill construction manual published by the Research Centre. 1980.

2. 'Anila-1: Low-cost windmill for pumping water,' by V. Geethaguru. Invention Intelligence, January 1980; 17-23.

3. 'Anila-1 and POGHIL, two low-cost wind pumps,' by V. Geethaguru and C.V. Seshadri. Proceedings of the National Solar Energy Convention 1980 held at Annamalai University, Dec. 19-21, 1980; 43-4.

POGHIL

Designers :

Mr. V. Geethaguru, Research Technologist and Dr. C.V. Seshadri, Director.

Industrial Affiliation :

Shri AMM Murugappa Chettiar Research Centre,
Photosynthesis & Energy Div.,
Tharamani,
Madras 600 042
INDIA.

Background :

After the successful trials of ANILA-1, the designers felt the need for another water pumping windmill which could harness the multi-directional winds in the interior areas.

Application :

For nursery irrigation, domestic water supply, shrimp farming, energy forestry, etc.

Type :

Horizontal axis, multi-directional, downwind sail wing device (See Fig. 21)

Suitability :

For interior regions prone to multidirectional wind ranging from 15-20 kmph.

Design Features :

The hub and sail assembly is similar to

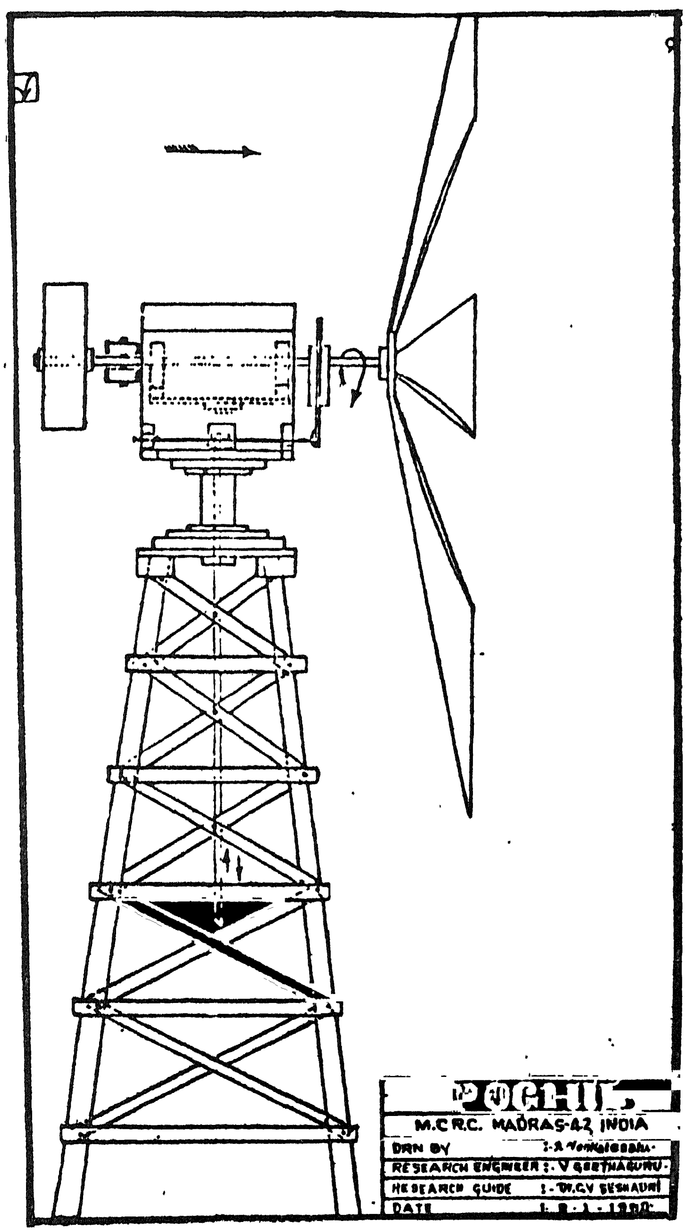


Fig. 21: Poghil Windmill

that of Anila-1, but the shaft is of iron and is mounted on a swivelling box. The rotor is in a downwind direction. The swivelling arrangement is made possible with a pair of iron tubes closely fitting as the "sliding pair."

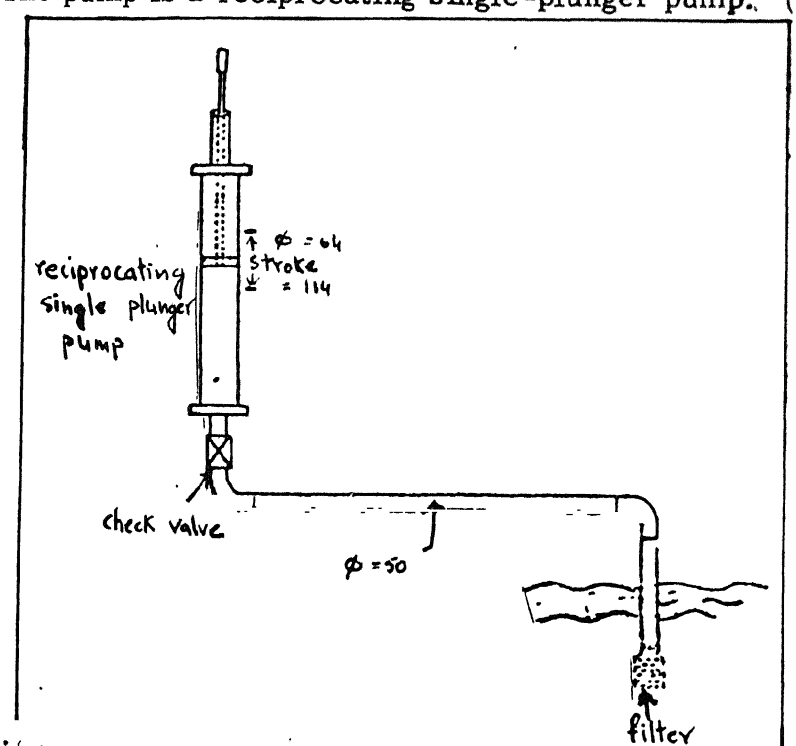
Power transmission

A wooden cam attached to the main shaft takes up the rotor torque and actuates and "F-lever." The flat area of the F-lever in turn operates the pump rod to lift water through a "twin-eye" link.

The shaft rolls in wooden bearing pillar blocks. A pair of planetary wheels attached to the shaft running on the box face holds the rotor against the impinging wind. A wooden flywheel attached to the other end of the shaft balances the rotor.

Pump

The pump is a reciprocating single-plunger pump. (Fig. 22)



Braking

The windmill can be braked by a wooden wheel (brakedrum) attached to the shaft with a wooden rider acting as the brake shoe. A rope passing through the shoe can be pulled from the ground to stop the rotor.

Technical data

Rotor diameter	335 cms
Solidity ratio	31.3
Tip-speed ratio	1.5 to 2
Cut-in windspeed	10 km/hr
Rated windspeed	20 km/hr
Pump diameter	5 cms
Pump stroke	11.5 cms
Pumping head	8 metres
Discharge	1500 lph @ 20 kmph windspeed.

Conclusions

The windmill can be made by village level artisans using materials normally found in villages. It does not incorporate any ball bearings. However, the fabrication involves some welding.

The design knowhow (patent applied for) is available free of charge to interested users. Engineering drawings and fabrication details could be obtained from the designers.

References

1. 'Anila-1 and POGHIL, two low-cost wind pumps', by V. Geethaguru and C.V. Seshadri. Proceedings of the National Solar Energy Convention 1980 held at Annamalai University, Dec. 19-21, 1980; 43-4.

2. Three-year annual review, Shri AMM Murugappa Chettiar Research Centre, Photosynthesis and Energy Division, June 1980 (Technical Notes No. 6).

CAZRI WINDMILL

Contact

Mr. S.C. Chowdhry.

Institutional Affiliation

Central Arid Zone Research Institute,
Wind Utilisation Section,
Jodhpur 342 003
INDIA.

Background

The windmill was fabricated and field-tested at the Institute as a part of a project in 1975.

Suitability

For regions prone to moderate multidirectional winds in the range of 8.5 to 15 kmph.

Type

Horizontal axis sail wing device (See Fig. 23).

Design features

Rotor assembly

The rotor is made from a 37 mm diameter axle having a crankshaft with a stroke of 20 cm. Three angle-iron pieces are interwelded and bolted at an angle of 120° on to a "disposal" brake drum (from a car or jeep) which is mounted on one end of the axle. The other end of the axle has double counterweights

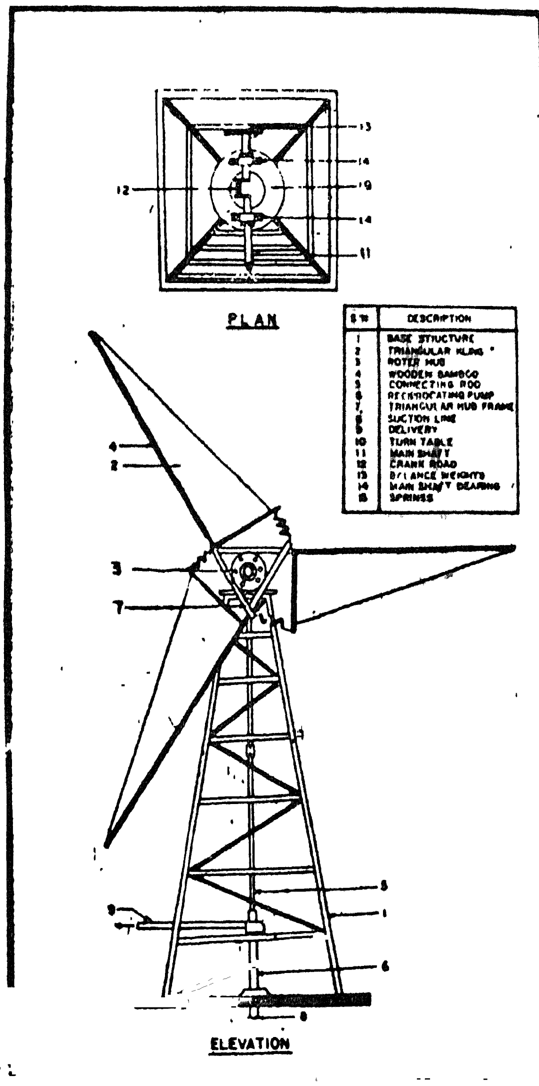


Fig. 23· The CAZRI Windmill

to balance the sail assembly as well as the connecting rod. (Fig. 24).

Auto-direction mechanism

A special feature of the windmill is an auto-directional mechanism to ensure quick response to changing wind directions. It consists of a round iron plate (56 cm diameter; 12 mm thick) resting on another plate (51 cm diameter) separated by a row of steel balls of 12 mm diameter placed in oil. A gasket is provided in a channel adjacent to the steel balls to protect them from the blowing sand.

The rotor assembly is mounted on the upper plate with pedestal bearings 25 mm off the centre to avoid damage from high windspeeds. (Fig. 24)

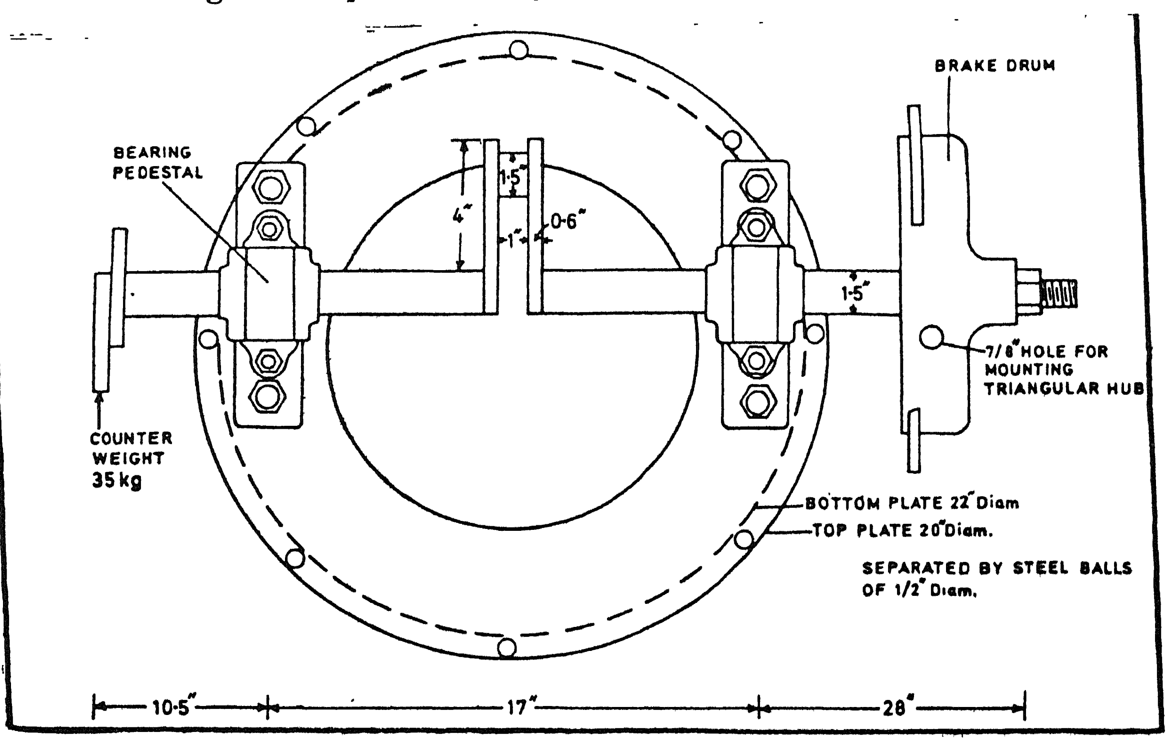


Fig. 24: Rotor assembly with Auto-directional Mechanism

Sails

The sails are three in number and are made of canvas cloth in a triangular shape (3 m long and 60 cm base). They are installed on bamboo poles of 4 m length connected to the angle iron pieces. Tension on the wings is maintained by the springs.

Power transmission

A connecting rod with a white metal bush mounted on the crank actuates a reciprocating pump.

Pump

The windmill uses a commercially available reciprocating pump with a brass cylinder of 6.4 cm diameter and 22.5 cm stroke. The windmill can pump water from 3.5 m below the ground.

Tower structure

A 6 m high wooden tower made from locally available "Dhawara" round poles supports the rotor and sail assembly. It is reinforced with angle iron at joints to make it robust enough to withstand wind storms. The poles are treated with bitumen and Aldrex as a protection against white ants and soil effects. A ladder is also provided for carrying out the necessary maintenance and repairs at the head of the windmill.

Technical data

Sail assembly diameter	6.7 m
Cut-in windspeed	8 kmph
Pump bore	4-6 cm
Pump stroke	22.5 cm
Suction head	3.5 m
Discharge at 8.5 kmph	225 lph
Discharge at 15 kmph	825 lph

Conclusions

The windmill can be built largely with materials and skills available in rural areas. However, the rotor fabrication involves some machining and welding. Performance tests conducted during 1976-78 indicated encouraging results, but no steps seem to have been taken for further demonstrations.

References

1. 'A low-cost sail windmill' by S.C. Chowdhry and A. Krishnan. Research & Industry, Vol.23; June 1978; p.81-4.

'Windmill for villagers' by S.C. Chowdhry and Purushotam Sharma. Urja, June 1980; p.239-40.

NAI WINDMILL

Contact : Gary Hirshberg.

Institutional Affiliation :

The New Alchemy Institute,
237, Hatchville Road,
East Falmouth,
MA. 02536,
U.S.A.

Background :

The present design is a cumulation of several years of research and experimentation, originating from the construction of a water pumping windmill during 1973-74.

Application :

Designed primarily for water pumping in aquaculture projects and for garden irrigation at the Institute.

Type :

Horizontal axis, downwind, sail wing device.

Design Features :

Rotor Assembly : (Fig. 25)

The rotor consists of three Dacron sails attached to guyed 3.05 m (10') masts. The rotor shaft is made from 50.8 mm (2") heavy wall conduit (water pipe) and the mast are each 3.05 m (10') sections of 25.4 mm (1") conduit. Each mast is guyed upwind and downwind. The downwind guys have turnbuckles for "coning" the rotor. This improves the rotor's yawing response to changes in wind direction. The sailwing rotor is designed to function downwind from the tower without a tail or rudder.

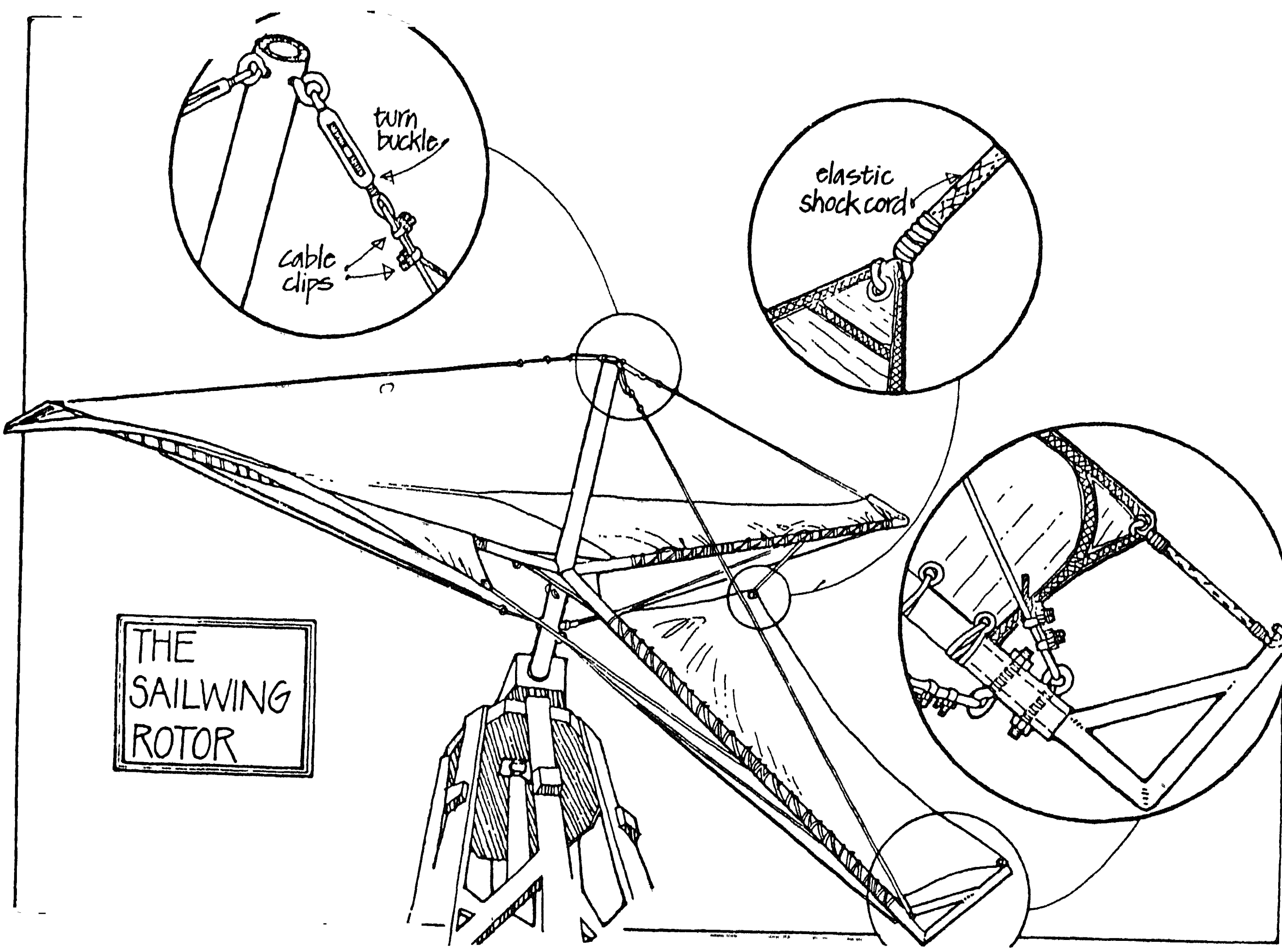


Fig. 25· New Alchemy Sailwing Rotor

Sail Assembly

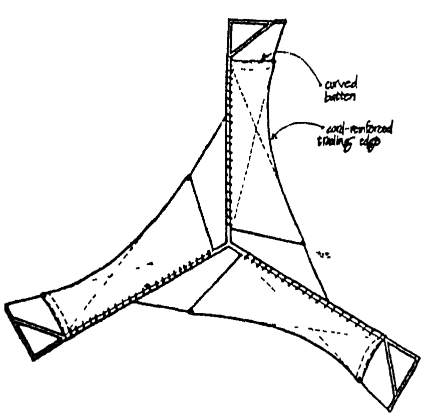


Fig. 26· Sail Assembly

Sails purchased from North Sails East, Connecticut are used. These sail use a 7.5 ounce Genoa style cloth with a special ultra-violet resistant coating. The sail pattern is shown in Fig. 26. Each sail is connected to the adjacent mast and to the top at its own mast by shock cords.

In low winds (5 to 15 mph) the taut sails catch the wind and drive the pump. In higher wind (15 to 40 mph) increased force on the sails press downwind, stretching the elastic shock card and allowing some of the wind to spill past the sails. This self-feathering mechanism allows for continuous pumping in higher winds.

In very high winds, the sails can be furled, by wrapping the root (the wide hub end) around the mast and securing it with the long cord.

Crankshaft :

The crankshaft incorporates several industrial-quality bearings and other components. The rotor shaft slides over a cold-rolled shaft which is press-fit into the two main flange bearings. The crank offset, fashioned from flat stock, gives a fixed 88.9 mm ($3\frac{1}{2}$") radius for a 177.8 mm (7") stroke. A small cold rolled steel shaft is pressed into this offset and two flange bearings are used to hang the vertical pump shaft.

Power Transmission :

Wind power is transferred along the rotating axle through a pair of bearing. The crankshaft transfers the axle rotation to vertical motion of the pump shaft.

Turntable :

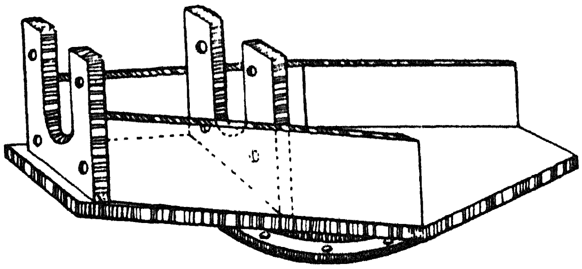


Fig. 27: Turntable and Transmission Mount

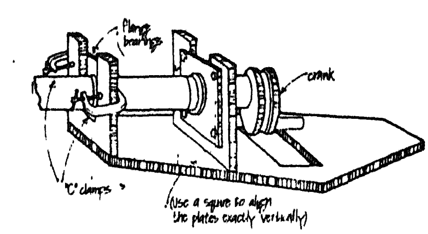


Fig. 28· Mounting the Crank End Plate

Figs. 27 and 28 shows the turntable and transmission mount. The 'U' shaped shoulder allows for the rotation of the main shaft and the flange bearings are mounted with the bolts as shown. Entire turntable assembly is mounted atop a heavy duty type bolt bearing.

Pump :

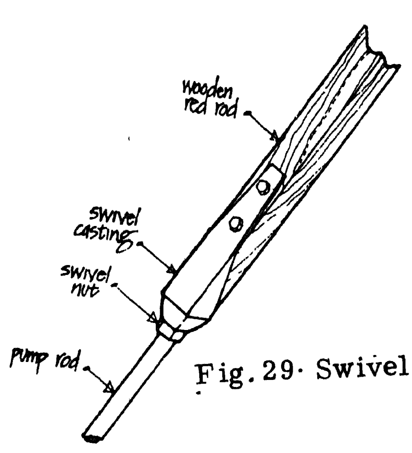


Fig. 29· Swivel Casting and Pump Rod

The pump assembly includes drop pipe, packer head, pump and pump rod. For pump shaft 25.4 mm (1") conduit are used and thread together the appropriate number of sections to accommodate the tower height. Red rod ($1\frac{1}{2}$" x $1\frac{1}{2}$") 38.1 x 38.1 mm with an adapter is used for security sake. At the base of the red rod is a commercial windmill swivel casting (Fig. 29) which affords both simple attachment to the wooden rod and low friction swivelling capability. The swivel is located at the lower end of the pump rod so that it is not stressed by the side-to-side action of the direct drive carnk offset above. The side-to-side motion is reduced as distance from the crank increases.

Braking :

The windmill rotor can be braked manually by means of a turn-out lever, attached to the pump rod above the pump rod swivel.

Tower :

The tower is made of galvanised steel with the tower top measuring 40.6 x 40.6 cm (16" x 16") for mounting the turntable bearing.

Conclusion :

The performance of the windmill as well as the installation, operation and economics of the New Alchemy Sailwing is included in 'The New Alchemy Water Pumping Windmill Book' by Gary Hirshberg. (July 1981)

Reference :

1. How to build the New Alchemy Sailwing Windmill by Gary Hirshberg, Jay Baldwin and Joe Scale. New Alchemy Technical Series No. 1, 1981 8p.

BISHOPS WINDMILL

Contact :

T.E. Sweeney,
166, Belford Ave.,
Rutherford, N.J. 07070,
U.S.A.

Background :

The conceptual design of the windmill described below was the result of a study undertaken for Rev. Luc Garnier, Anglican Bishop whose intention was to assist peasants of Haiti in combining wind-power and fish farming.

Application :

Water pumping in fish farming.

Type :

Horizontal axis, upwind, sail-wing device (Fig. 30 on next page).

Suitability :

Regions affected by trade winds.

Design features :

Rotor Assembly :

It consists of a pair of circular discs (A) that comprise the rotor hub and to which are attached 3 sails (B) (Fig. 31). Each sail is connected by a peripheral cable (N) for the purpose of structural integrity. There is a lance (L) (Fig. 30) protruding forward from the rotor and from the tip of the lance, drag cables (M) are fitted to each of the sail-tips.

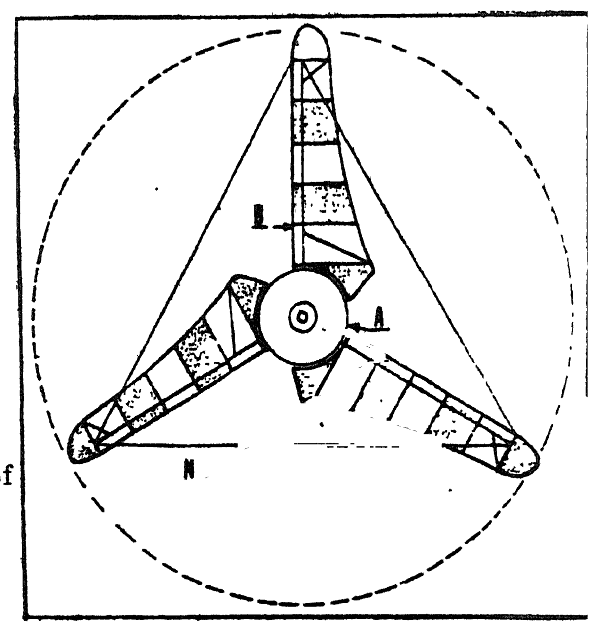


Fig. 31: Rotor Platform

Sails :

The sails, 3 in number, are made out of Dacron sail cloth.

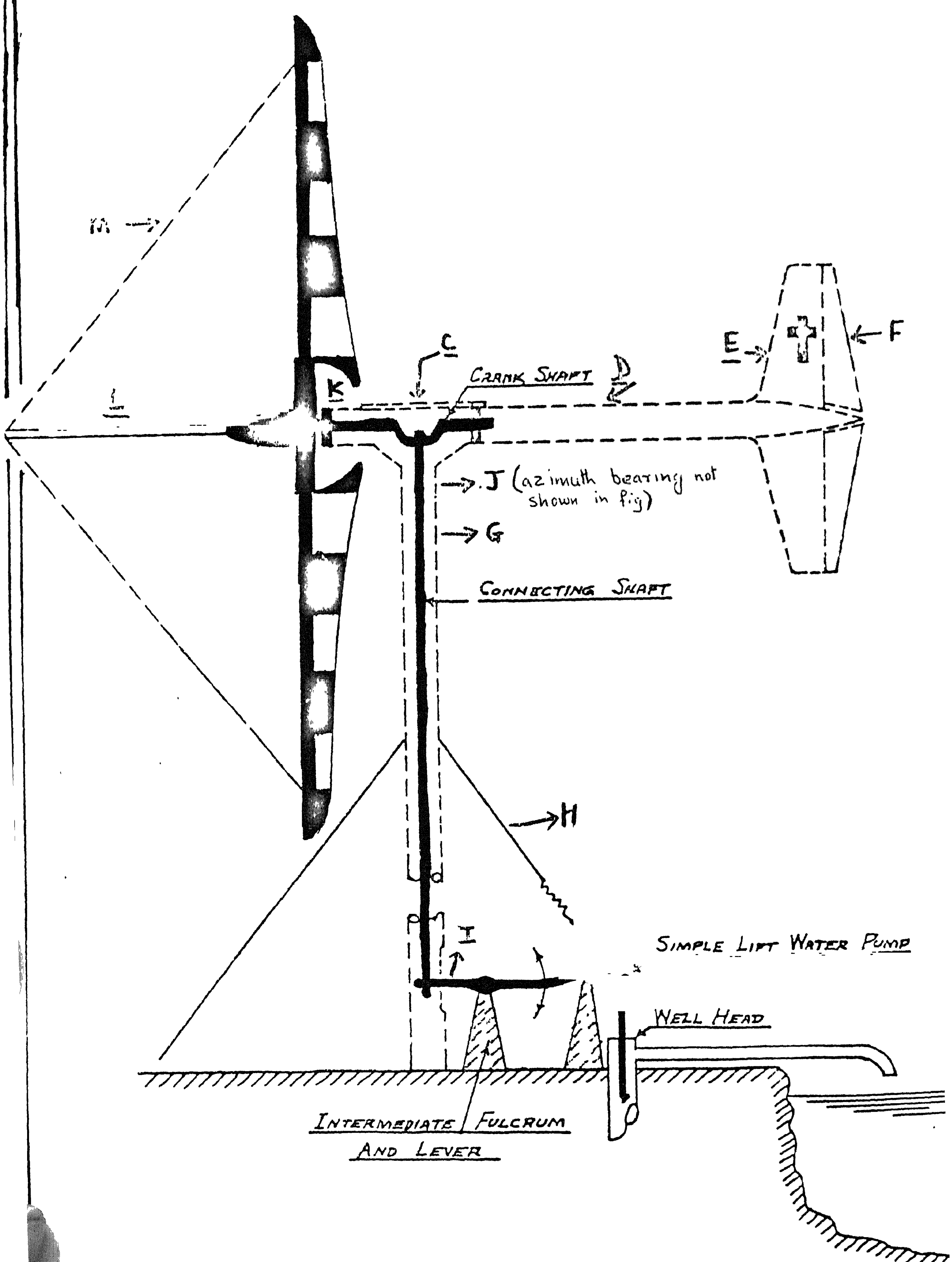


Fig. 30: Bishops Windmill

Boom and Mast :

The rotor assembly is fitted to the horizontal boom (D) by means of the rotor shaft through a thrust bearing (K) and a self-aligning bearing immediately up-stream of the boom-mast fitting (C). Both the boom and mast (G) are aluminium tubes welded at their juncture. Immediately below the boom-mast fitting is the azimuth bearing (J) which permits the entire upper assembly to constantly and automatically orient itself into the wind.

Tail Assembly :

The tail end of the boom is fitted with a fin (E) for adequate directional stability and trim tabs (F) to offset the torque produced by the operating windmill.

Transmission :

At the juncture of the boom and mast is a crank which sets the connecting shaft into reciprocating motion, which is transmitted via an output shaft (I) to a simple lift-water pump with the aid of a fulcrum and lever mechanism.

Foundation :

Two types of foundations are suggested for solid terrain (Fig. 32) and for more sandy or muddy ground. In the second type it is suggested that a disc of concrete be used as the supporting platform. In both cases the mast is pin-connected to the central foundation and stabilized in the vertical position by shrouds as shown in figure.

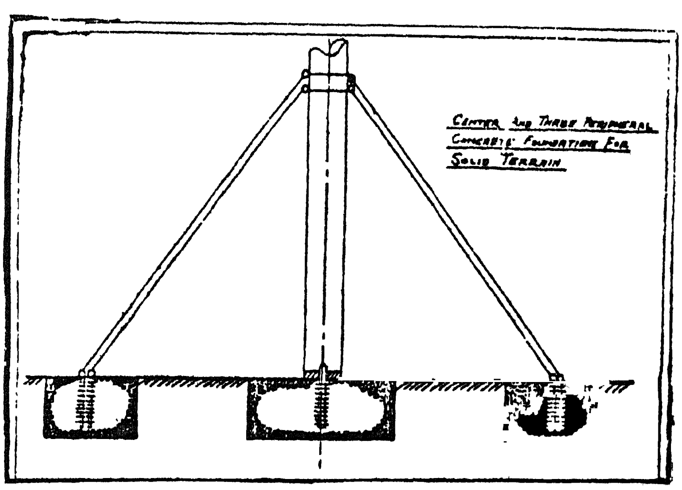


Fig. 32: Foundation for Solid Terrain

Conclusion :

The windmill structure is largely aluminium tubing, steel cables, marine fittings, and dacron cloth for sails. However, the windmill can be modified by using locally available materials like wood (bamboo for sail-spars etc.).

Reference :

1. The Bishop's Windmill by T.E. Sweeney. July 1976. 25p. (Available from Volunteers in Appropriate Technology, 3706 Rhode Island Ave., Mt. Rainier, Maryland 20822).

BAMBOO-MAT WINDMILLS

Institutional Affiliation :

National Energy Administration,
Wind Energy Unit,
Pibultham Villa,
Kasatsuk Bridge,
Bangkok 5,
THAILAND.

Background :

Several types of windmills are widely in use in Thailand in the region near Samut Songkram.

Application :

For brine pumping at the salt farms.

Type :

Horizontal axis, slow-speed, bamboo-mat sail windmill, (Fig. 33)

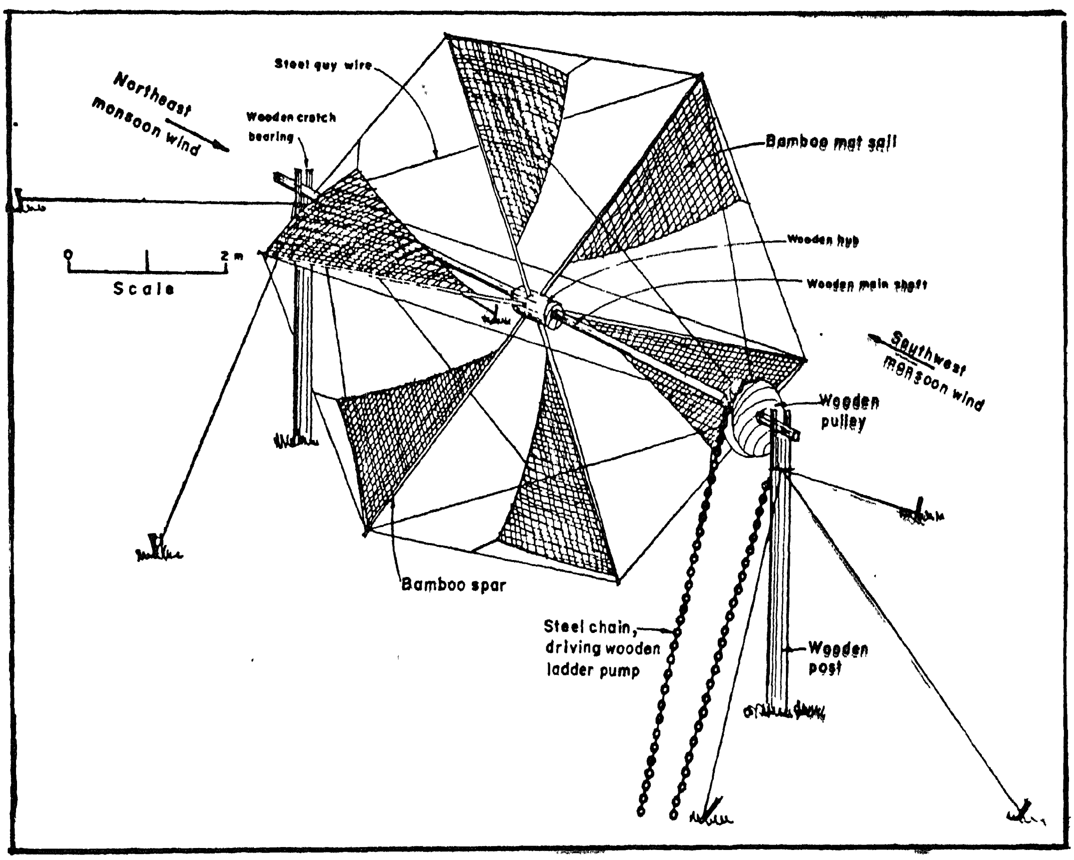


Fig. 33· Thai Sail Rotor Water Pump

Suitability :

Regions with average windspeeds ranging from 13-17 kmph.

Design Features :

Rotor Assembly :

The rotor which is 7 to 8 m in diameter consists of a 30 cm diameter wooden hub mounted in the centre of a 5 m long, 10 cm square main shaft. Six bamboo spars radiate from the hub, the tips of each spar are braced by steel wires to points near the opposite ends of the main shaft. Each end of the main shaft is rounded to fit in a notch (journal bearing) cut in the top of each of the two vertical wooden supporting poles.

Sails :

There are 6 sails made of triangular mat woven from split bamboo and reinforced with nylon cord. Each sail is fastened by wooden slats and nails along its long edge to a bamboo spar radiating from the hub. The apex of each sail is held tight by a nylon cord loop connected to a 1 cm diameter nylon rope which is stretched around the rotor circumference between the tips of each spar. A manually activated, quick-release sail-feathering device is incorporated at each loop connection.

Power Transmission :

Power is transmitted 12 m diagonally by a steel chain of 2. 5 cm along open-links, from a 0.7 m diameter wooden pulley mounted at one end of the main shaft to a 6. 5 m diameter wooden pulley near the ground which drives the power shaft of an open-trough wooden-pallet chain pump,

Pump :

The open trough square-wooden pallet chain pump used with the windmill is illustrated in Fig. 13.

Tower Structure :

The stationary support structure of two wooden poles is set in the ground in a fixed direction to receive the winds of the southwest monsoon from one side and the winds of the northeast monsoon from the other side.

Operating Data :

Rotor diameter : 7 to 8 m.
Starting wind velocity : 1.7 m/sec.

Average Windspeed	Pumping head	Average discharge
kmph	m	litres/sec
17	0.55	17.3
13	0.60	12.8

Conclusion :

These bamboo-mat sail windmills can be locally made using a minimum of carpentry skills and tools.

Detailed technical drawings of this type of windmill have been prepared by the Agricultural Engineering Division, Ministry of Agriculture and Cooperative, Thailand.

Reference :

1. 'Research, Development and Use of Wind Energy in Thailand' by the National Energy Administration (Thailand). Proceedings of the Meeting of the Expert Working Group on the Use of Solar and Wind Energy. Energy Resources Development Series No. 16, New York, UN, 1976. p. 108-114.

CRETAN WINDMILLS

Windmills of Lassithiou, Crete

Background :

Prominent in the Mediterranean region and historically used for grinding corn and pressing olive oil, these windmills were adapted in Crete for water pumping. At least 6,000 of these devices are now in use in the broad fertile plain of Lassithiou which is isolated in the mountains and some hundreds are also in use in other parts of Crete.

Applications :

Pumping water for seasonal irrigation of intensively cultivated plots of vegetables and grains.

Type :

Horizontal axis, mono-directional sail-wing windmill. (Fig. 34)

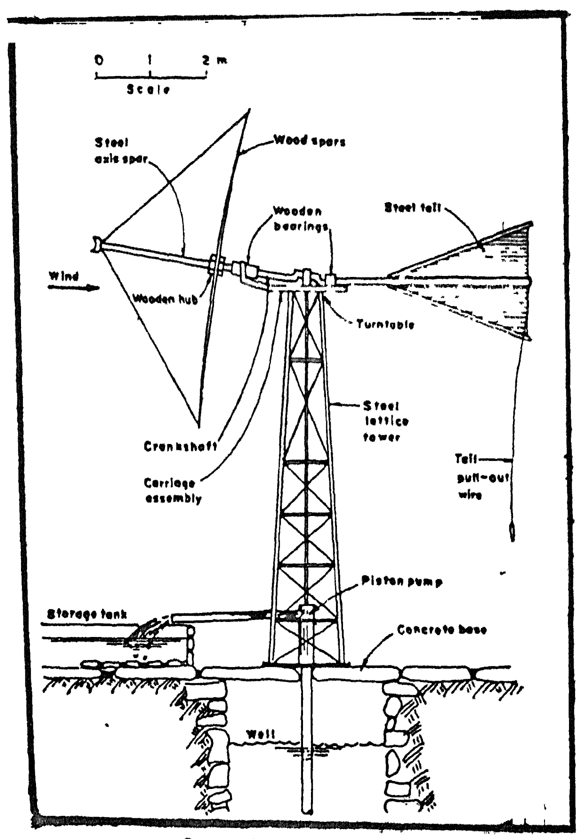


Fig. 34: Cretan Windmill

Suitability :

Regions with average wind of 8 kmph.

Design Features :

Rotor Assembly :

It consists of a wooden hub of 30 cm diameter. The hub slips over a crank shaft made of 5 cm diameter, 160 cm long mild-steel rod. 8 wooden spars each 2.7 m long radiate out from the hub to form a total windmill diameter of 5.4 m. An axial spar of angle iron extend 2 m out in front of the hub along the main axis of the crank shaft. Steel wires radiating back and out from the end of the axial spar to the tips of the radial spars provide bracing against strong winds, and steel wires between the tips of all the radial spars provide additional bracing. A 60 cm diameter flat steel ring around the hub is bolted to each spar to keep them secured tightly within the hub.

Turntable :

The turntable, riveted to the top of the 4 tower legs, is made of a 160 cm long piece of 5 cm mild-steel angle iron bent into a 50 cm diameter ring to form a flat horizontal greased bearing surface for the carriage. The carriage, rectangular angle iron frame 35 cm wide and 140 cm long, connected by 4 bolts to two 35 cm long pieces of angle iron riveted to a 45 cm diameter flat steel ring which rotates on the bottom inside surface of the turntable ring. This arrangement keeps the carriage firmly attached to the top of the tower, at the same time allowing it and the attached shaft, sails, etc. to rotate when the wind direction changes.

Tail Assembly :

A triangular tail of corrugated sheet steel 1.5 m x 1.5 m x 1 m is supported by two 2 m long pieces of angle iron from the rear of the carriage. (Some units have manually-operated tail pole with no vane).

Power Transmission :

The crankshaft incorporates a U-shaped crank which gives a stroke of 15 cm. A 2 cm diameter steel connecting rod attached with two bolts to a wooden crank bearing transfers the rotary motion of the crankshaft into vertically reciprocating motion of the pump piston.

Pump :

A 13 cm diameter, 15 cm stroke piston pump made from a discarded cannan shell and fitted with a leather foot valve and leather sealed piston, is mounted on the base in the centre of the tower. A 15 cm thick concrete slab covering a 2 m diameter, 7 m deep well forms the base of the windmill.

Braking :

The windmill can be stopped during operation by pulling the tail chord so that the surface of the sails is parallel to the wind.

Operating Data :

The Cretan windmill starts pumping at a wind velocity of 8 kmph and reaches optimum performance of 25 RPM at 13 kmph.

Lift : 5 cm.
Discharge : 3000 litres/hr.

Conclusion :

All the wooden bearings and spars are of local origin. The metal shaft and lengths of angle iron are fabricated using ordinary blacksmith's tools and skills. Recently some electric welding has been utilised for construction of improved crankshaft and huba.

The Cretan design has gained widespread use and several versions of this design have been constructed in different countries.

References :

1. "Development of wind energy utilization in Asia and the Pacific." Proceedings of the Meeting of the Expert Working Group on the Use of Solar and Wind Energy. Energy Resources Development Series No.16. New York, UN, 1976. p.65-66.

MADURAI WINDMILL

Designers :

Marcus Sherman.

Institutional Affiliation :

Originally developed at Madurai, S. India for Madurai Windmill Committee by Marcus Sherman who is currently at Volunteers in Technical Assistance, Asia Field Office, 48, Soi Area 1 Phaholyothin Road, Bangkok 4, Thailand.

Background :

This windmill is an adaptation of the traditional Greek sail-wing windmill design and is the fourth in the series of prototypes that have been built near Madurai. The windmill was completed in March 1975.

Application :

Pumping water from open wells.

Type :

Horizontal axis, multidirectional sail-wing windmill. (Fig. 35)

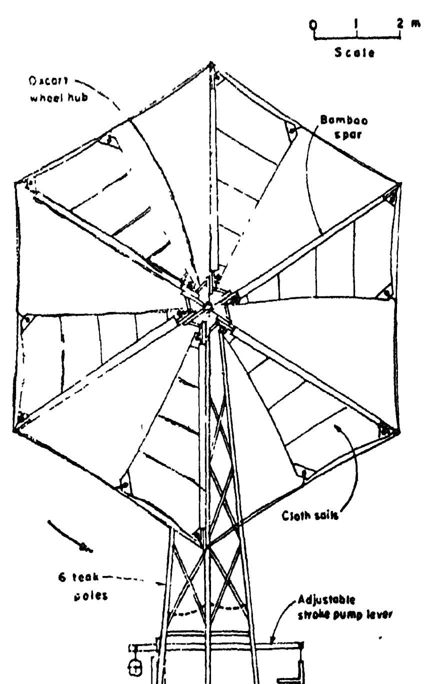


Fig. 35: Madurai Prototype

Suitability :

In regions with both low and high wind velocities.

Design Features :

Rotor Assembly :

The rotor consists of an ox cart wheel bub with 8 wooden spokes. The spokes are braced to each other with wood. A bamboo arm is attached to each spoke with two "U" bolts. A hole in the centre of the hub fits onto the front and of the crankshaft and is secured by a 1.6 cm bolt "Colter pin." Eight 4.5 m long bamboo poles radiate out from the bub to form a total windmill diameter of 10 m. A central supporting spar of bamboo extends 2 m in front of the hub along the main axis of the crank shaft, which is made of 3.2 cm mild-steel rod. Eight single-strand steel wires radiate out and back from the tip of this central spar to the tip of each bamboo arm for providing bracing against strong winds. Wires between the tips of all the radial arms provide additional bracing.

Sails :

There are 8 right-triangular sails made from khakhi cloth. A 10 cm guide sleeve on the hypotenuse side of each sail enables it to slip on and off the bamboo arms. The tip and hub ends of the sleeve are tied securely to their respective ends of the bamboo arms. The 90° corner of each sail is secured by a rope of coconut husk fibre to the tip of the adjacent arm.

Turntable ·

The base of the turntable consists of a steel truck tire rim with an inside diameter of 23 cm. The truck rim is drilled and bolted to the tops of the teak poles. The smooth circular platform by the inside of the rim is the bearing surface upon which the turntable carriage sits and rotates. The turntable carriage which is made of 1.5 m x 36 cm rectangular iron angle frame is secured to the turntable base by 4 bolts which are fixed to two 25 cm pieces of angle iron which rotate on the bottom inside surface of the turntable base. This arrangement keeps the carriage firmly attached to the top of the tower and enables the rotor and the tail to turn when the wind direction changes.

Tail Vane :

A 1.3 m x 2.5 m rectangular tail made of bamboo melting in a light teakwood frame is supported by a 3.7 m long piece of heavy duty bamboo poles from the rear of the turntable carriage with two "U" bolts and is braced with guy wires. The tail keeps the sail always facing the wind.

Transmission :

The crankshaft directly transfers the horizontal rotary motion from the windmill sails into the vertically reciprocating motion which operates the piston pump. The crankshaft which has a crank of 3.2 cm mild-steel rod welded at the centre gives a total stroke of 13 cm.

Pump :

The pump used in this windmill is a piston pump with a 10 cm bar and a 61 cm maximum stroke. The pump is attached in the bottom of the well at the end of 9.1 m of 5 cm steel pipe suspended from a stone pillar. The top of the pump piston connecting rod passes up through and out of the top end of the pipe and is secured to the end of the variable stroke pump lever. A 2.5 m long 5 cm x 20 cm teak beam is mounted at the base of the windmill by a fixed axis point at one end and attached to the pump piston rod at the other end. The bottom end of the wooden crankshaft connecting rod is fixed to this lever by a steel bracket at a point between the ends of the lever. This point can be varied to change the length of stroke delivered to the pump connecting rod. The pump lever is also important because it increases the stroke of the crankshaft from 13 cm at the crankshaft to a minimum of 18 cm and a maximum of 36 cm at the pump connecting rod.

Tower ·

The tower is made of six 8 m long teak poles bolted at the bottom to the steel anchors in the foundation and bolted at the top to the base of the turntable. The base of the tower is 1.8 m in diameter. There are two sets of cross braces nailed to the inside of the tower and a set of internal guy wires. Ladder steps are nailed to the inside. Five additional steps nailed around the tower 1 m above ground provide a standing platform for the operator while he is adjusting the sails.

Braking ·

The windmill can be manually braked by pulling the ropes hanging from the end of the bamboo tail boom. This pulling of the tail into the wind turns the windmill carriage so that the sails turn out of the wind and stop rotating. Alternatively, automatically braking can be achieved by using a 1.3 cm coconut fibre rope as the tension member from the 90° corner of each sail to the tips of the adjacent arm. In high wind this weakest connection in the energy transfer breaks before load on the other material becomes destructive.

Technical Data :

Rotor diameter	10 m
Pump diameter	10 cm bore
Pump stroke	13-35 cm (variable)
Starting wind velocity	6 km/hr

During April 1975, the windmill was performing as under :

Windspeed	Head	Discharge
6-8 km/hr	9.2 m	1635 litres/hr

Conclusion :

The basic structure is made of teak and bamboo wood. A steel rod is used for the crankshaft, steel wires for guying and khadi cloth for sails. There is some welding involved in the construction of the crank. There are no gears or pulleys in the driving mechanism.

Design optimisation and testing was carried out by the Agricultural Engineering Division at the Indian Agricultural Research Institute (Dairy Road, New Delhi 110 012).

Reference :

1. "The design and construction of an appropriate water pumping windmill for agriculture in India" by Marcus M. Sherman. Appropriate Technologies for Semiarid Areas: Wind and Solar Energy for Water Supply. Berlin, German Foundation for International Development. 1975. 95-111.

POLOMO WINDMILL

Designers :

E.O. Pullock, J.R. Swart and others.

Institutional Affiliation :

The American Christian Mission,
Omo, Lake Rudolph,
ETHIOPIA.

Appraisal : Peter Fraenkel,
Intermediate Technology Development Group,
9, King Street,
LONDON WC2E 8HN.

Background :

The windmill was designed in 1974 for substituting further imports of American Dempster windmills which were found successful in irrigating the Gemu Gufa province on the west bank of the Omo River in Ethiopia.

Application ·

Low lift irrigation with suction lift up to 6 m.

Type ·

Horizontal axis, 'Cretan' sailwing device. (Fig. 37)

Suitability :

Areas prone to multidirectional winds in the range of 16-24 kmph.

Design Features :

Rotor Assembly :

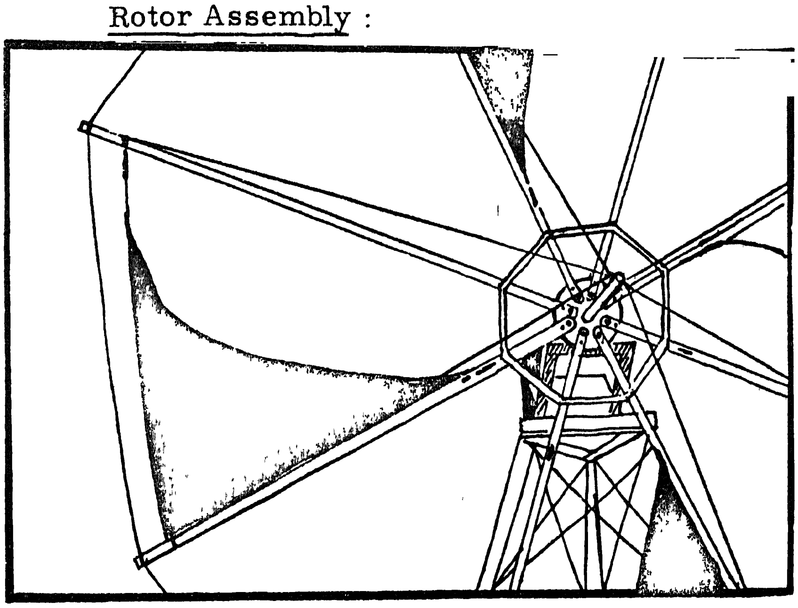


Fig. 37: Central Hub

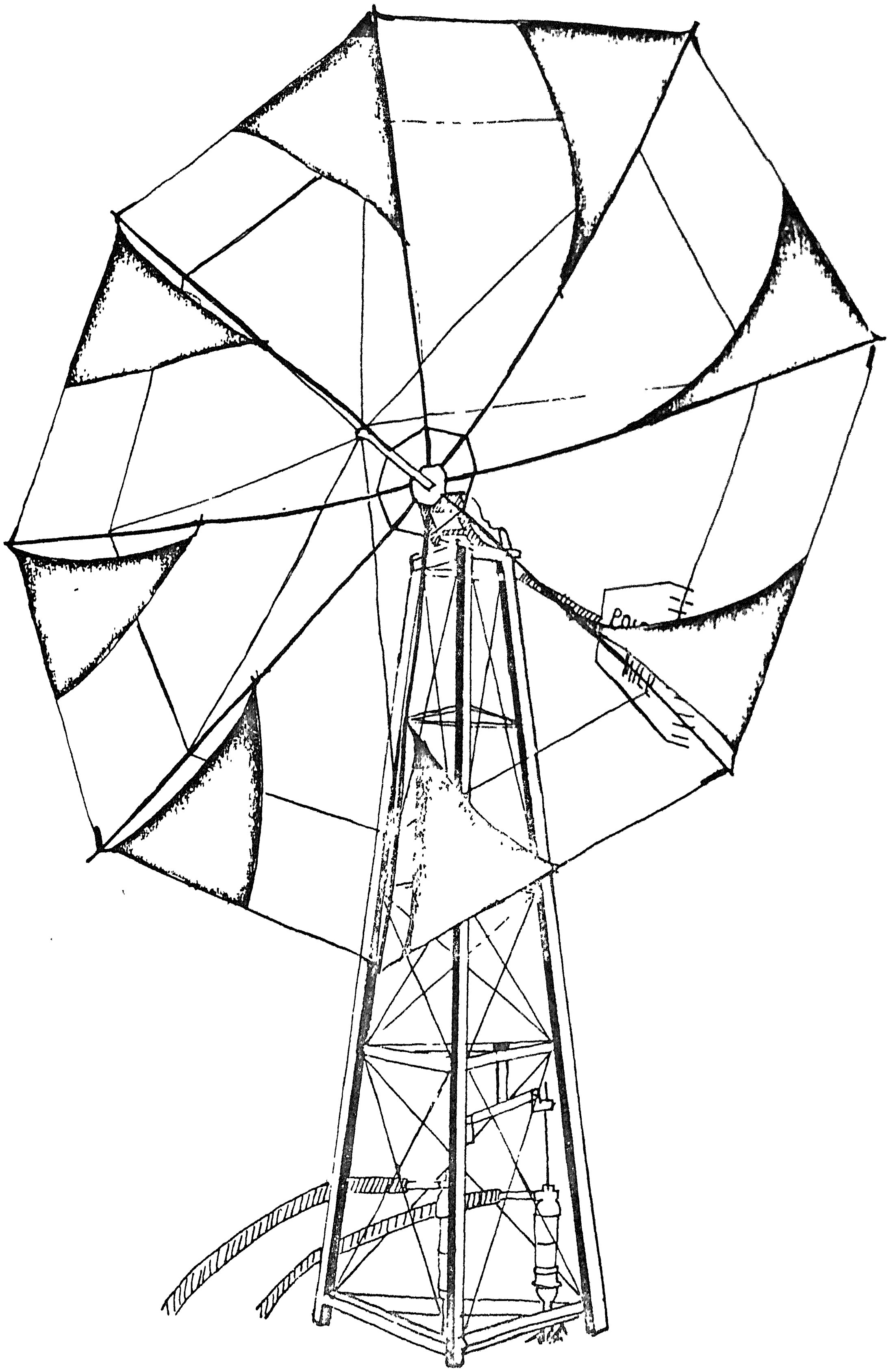


Fig. 36: Polomo Windmill

It consists of 8 arms radiating from a central hub. The whole structure is braced with wires radiating from an extension shaft mounted on the hub to prevent axial distortions of the arm and by wires connecting the tips of the arms to control radial movement. The arms are of 19 mm (3/4") black water pipes and curved forward slightly giving a negative coning in order to give sufficient clearance between the wheel and the tower. The central extension from the hub to carry the bracing wires, is made from 2 lengths of 25.4 mm x 25.4 mm (1" x 1") angle welded with their flange ends in contact to make a square cross-section, and the bracing wires consist of standard galvanised fencing wire.

Sail Assembly :

The sails are eight in number with a triangular shape and are made of Dacron cloth with their leading edges fixed to the arms. Rubber loops are attached to the corners of each sail with lengths of polypropylene rope. This enables the sails to be rapidly fitted or removed by attaching the loops onto metal hooks welded at suitable points on the arms of the wheel. The rubber keeps the sail stretched into an effective shape for capturing the wind.

The number of sails actually used depends on the wind at the time. The sails are put up in the morning and adjusted, while the windmill is in use; when work is finished in the fields, the sails are removed for safe-keeping (which also protects the mill from damage in case of a sudden storm and high winds).

Steering :

The head assembly consists of an angle iron frame carrying two mountings for the main shaft bearings and the side members extend backwards to include an integral tail unit. The frame rides in a 3.2 mm x 12.7 mm (1/8" x 1.2") flat-bar ring of 30.5 mm (12") dia. welded onto the top frame of the tower. The head is prevented from lifting by four hooks bent from flat bars which projects down through the centre of the frame and curve around underneath the ring in the top of the tower.

Tail Assembly :

The tail unit is carried on a pair of 38 mm x 38 mm ($1\frac{1}{2}$" x $1\frac{1}{2}$") angles from the rear of the head frame; it consists of a suitably shaped panel of flat galvanised sheet steel bolted between the flanges of the tail boom with extra vertical flat bar stiffeners.

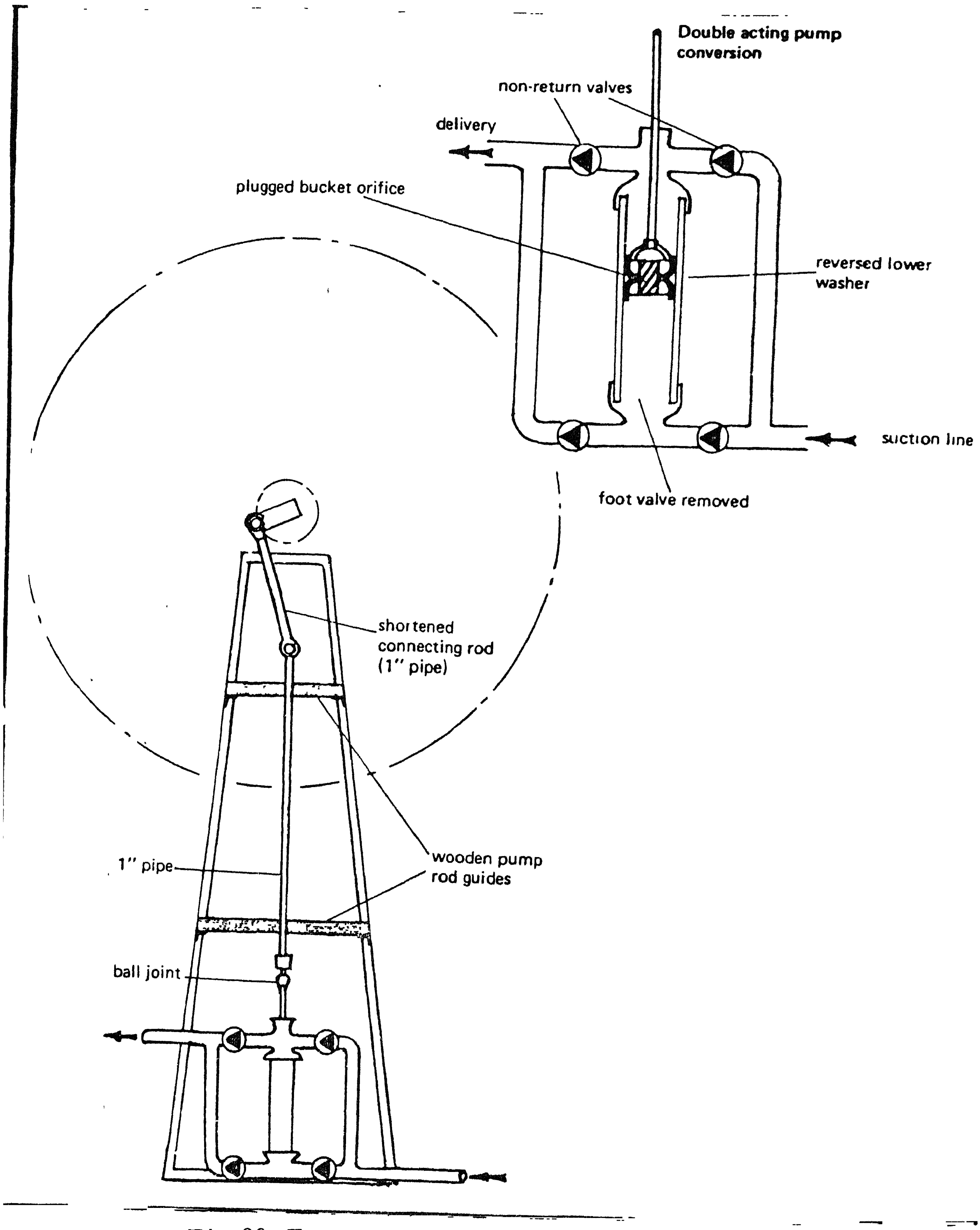


Fig. 38· Transmission for a Double-Acting Piston Pump

Power Transmission :

The pumps are driven from the tower head by a crank and a connecting rod made from 9 mm (3/4") black water pipe. A simple ball and socket joint allows for non-alignment of the head and pump and also allows the top part of the connecting rod to turn with the windmill head when it moves to face changing wind directions and this forms the link between the pump rod extension and the connecting rod. The pump rod extension is kept in alignment with the pump by a wooden cross-head in the form of a plank straddled to the tower at the correct level with a hole bored in it for the rod.

The top of the connecting rod has a split piece of water pipe welded to it with reinforcement flanges for support and to prevent buckling. The split water pipe has two drilled lugs to allow it to be bolted around the crank journal on the head. Fig. . 38. shows stiffened transmission for a double-acting piston pump, which can be alternatively used by converting a single acting pump into a double-acting piston pump.

Pump :

The piston pumps used with the windmills were those manufactured by Dempster Industries. Dempster originally supplied a 7.6 cm (3") diameter cast steel pump with a brass cylinder lining and gun-metal bucket and value components, plus a single leather washer. Later, they substituted an alternative 7.6 cm (3") diameter pump with a thick-walled PVC cylinder and two leather washers on a similar gun-metal bucket. The disc values in both cases were of gun-metal and brass. The Dempster pumps operate with a stroke of 17.7 cm (7") on the sail windmill.

The windmill draws water from the river through a pvc plastic pipe of 38 mm ($1\frac{1}{2}$" dia.). The pipe is attached to the suction and of the pump and carries a brass foot valve at its lower end. The foot valve is supported by a float made of styrofoam (polystyrene) block-fitted into half an oil barrel for preventing the foot valve from getting clogged with silt. The outlet for the pump is via a standard "T" pipe fitting, an alive-wood plug bored to take the pump plunger as the sealing device.

Tower :

The 3-legged tower, 3.6 m (12 feet) in height is built of angle iron and needs no foundation other than impacted soil.

Operating Data :

Technical and performance data of 3.35 m (11 ft.), 4.27 m (14 ft.) and 4.88 m (16 ft.) Omo Windmill.

	Omo - 11	Omo - 14	Omo - 16
Rotor dia (m)	3.4	4.3	4.9
No. of sails	6	8	8
Pump size (cm)	7.6 bore 17.8 stroke	7.6 bore 17.8 stroke	7.6 bore 17.8 stroke
Rated pumping output (1 ph)	1421	3600	6915
Cut in windspeed (kmph)	-	-	3.25 (2.5 m/sec)
Cut-off-windspeed (kmph)	above 6.5	above 6.5	above 6.5

Conclusion

These units can only be constructed by someone with basic technical knowledge. Erection is possible with simple material and aid. The equipments required to build this windmill include an electric arc welding set, an electric drill, a wood lathe and hand tools. Thread cutters are also necessary for piping work. 19 windmills were reported to be in use in 1975. Based on tests conducted on the windmill, several modifications and recommendations have been suggested. (Ref. 1)

References

1. Food for Windmills by Peter Fraenkel. London, Intermediate Technology Publications Ltd., 1975. 74p.

2. Operating Data taken from 'Practical Applications of wind-powered Water-pumps.' Economic and Social Commission for Asia and the Pacific, Workshop on Biogas and other Rural Energy Resources (Energy Resources Development Series No. 1a). New York, United Nations, 1979. p. 95-96.

NAL WINDMILL

Contact ·

Dr. S.K. Tewari, Scientist.

Institutional Affiliation :

National Aeronautical Laboratory,
Post Bag No. 1779,
Bangalore 560 012,
INDIA.

Background :

NAL in 1977 decided to design a windmill for water pumping. This resulted in designing and fabricating a prototype based on Greek sail windmills.

Application :

Primarily for irrigation in small farms from shallow open wells.

Type :

Horizontal axis, sail-wing device (Fig. 39).

Suitability :

Areas prone to multidirectional winds in the range of 7-12 kmph.

Design Features :

Rotor Assembly : Fig. 40

It consists of a hexagonal hub plate on which 6 tubular steel spars of 45 mm outer dia. are mounted (Fig. 40). The rotor hub is keyed to the shaft which is about 800 mm away from the centre of the output shaft in order to have sufficient clearance between the rotor spars and the tower. The end of the spars are connected by means of steel wire ropes of 3 mm diameter. The rotor has been designed to face the wind ahead of the tower. The end of the spars are connected through wire ropes to a forward axial projection from the hub plate. This arrangement adds stiffness in the bending mode to spars when sails are opened to face the wind.

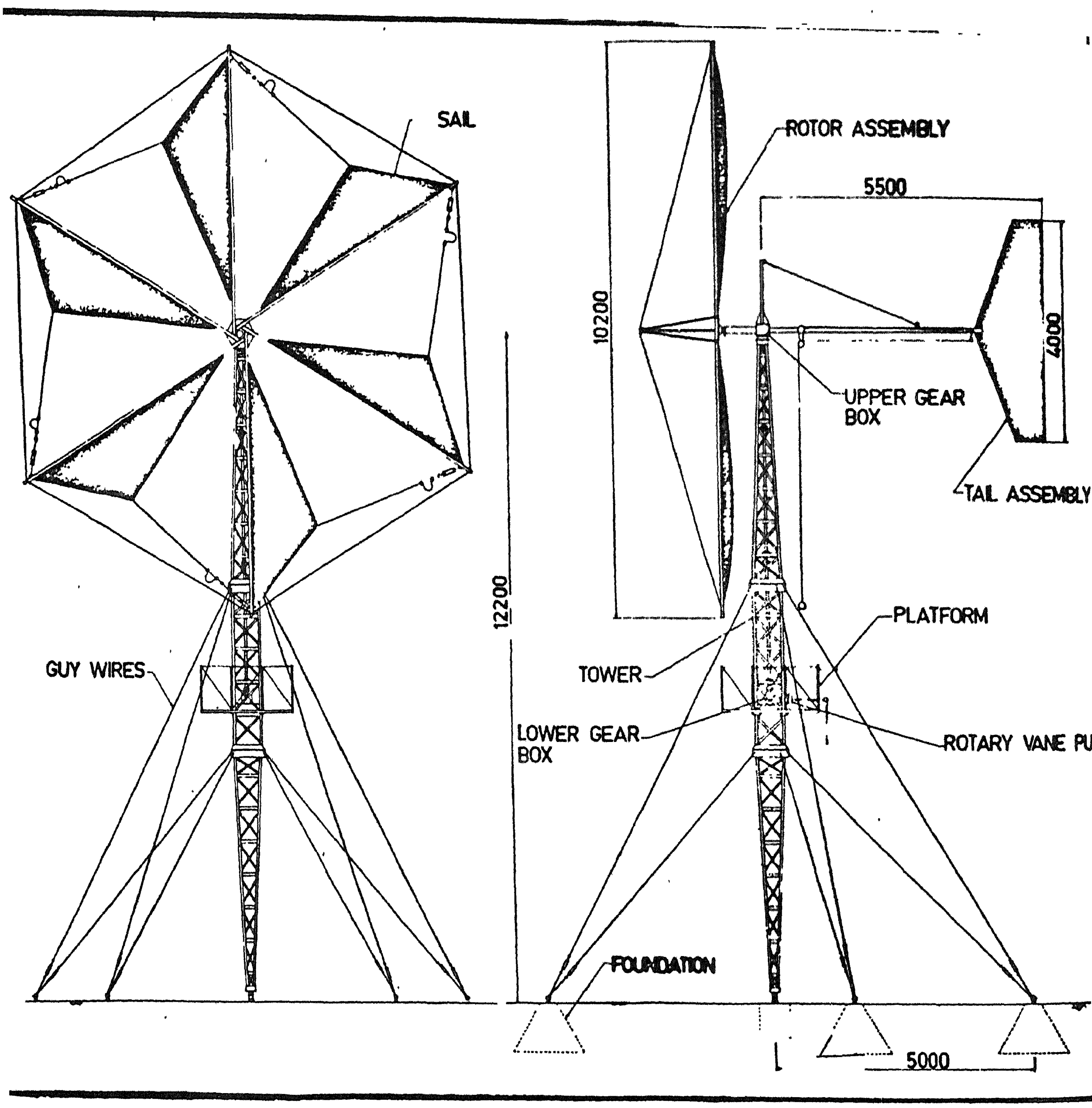


Fig. 39· NAL Sail Windmill

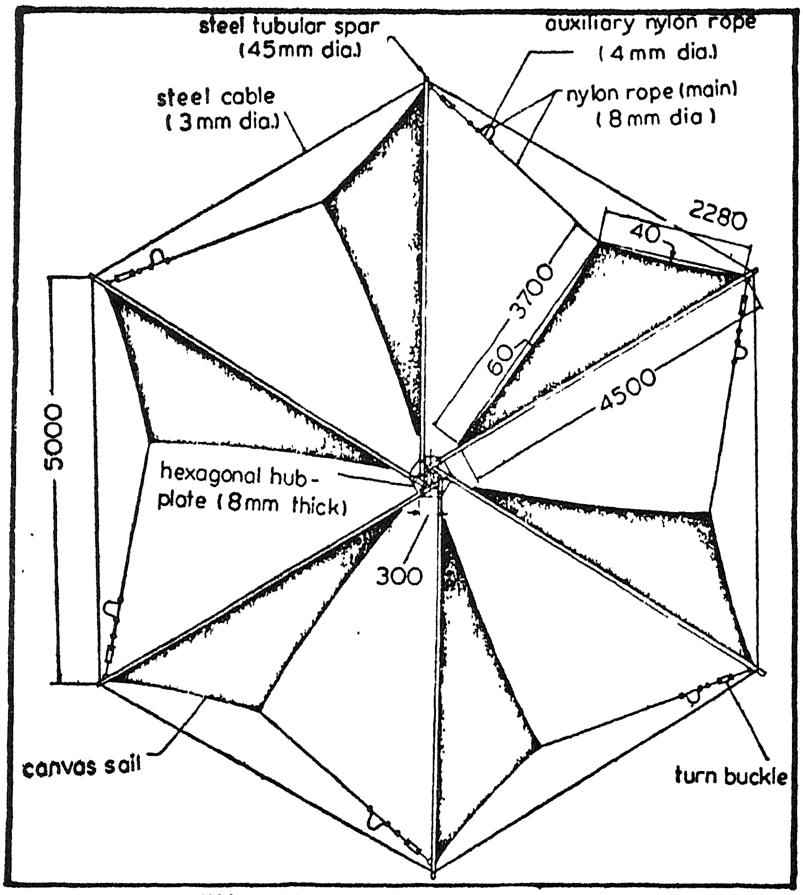


Fig. 40: Rotor Assembly

Sail Assembly :

The sails, triangular in shape, are 6 in number and made of canvas cloth. The loose end of the sails is connected on to a hook welded on the next spar by means of a nylon rope of 8 mm diameter and a turn-bucket.

Safety Device :

As shown in Fig. 41 a loop is made from the nylon rope such that the load from the sail is first transmitted to the next spar through a portion of a 4 mm nylon rope. This rope ruptures under a tensile load of about 200 kg which occurs at 15 m/sec windspeed. When the thinner rope snaps the loop straightens and the sails become slack. This safety mechanism based on rupture of the thinner rope is expected to protect the rotor from occasional gusts. During windy months, the sails should be opened only partially by wrapping it around the mast.

Tail Assembly :

The tail of the windmill is 5.5 m long and made of canvas mounted on a framework of conduit pipes. The tail vane has a 6 sq. m. area. The tail is provided with a hinge around which it could be tilted manually through 30^{o} and locked in position by means of ropes.

Power Transmission :

The rotor shaft is coupled to a pair of bevel gears to change the axis of rotation of shaft by 90 and the output shaft is passed through the centre of the tower. The rotor and the bevel gears are mounted on either end of the shaft. (Fig. 41)

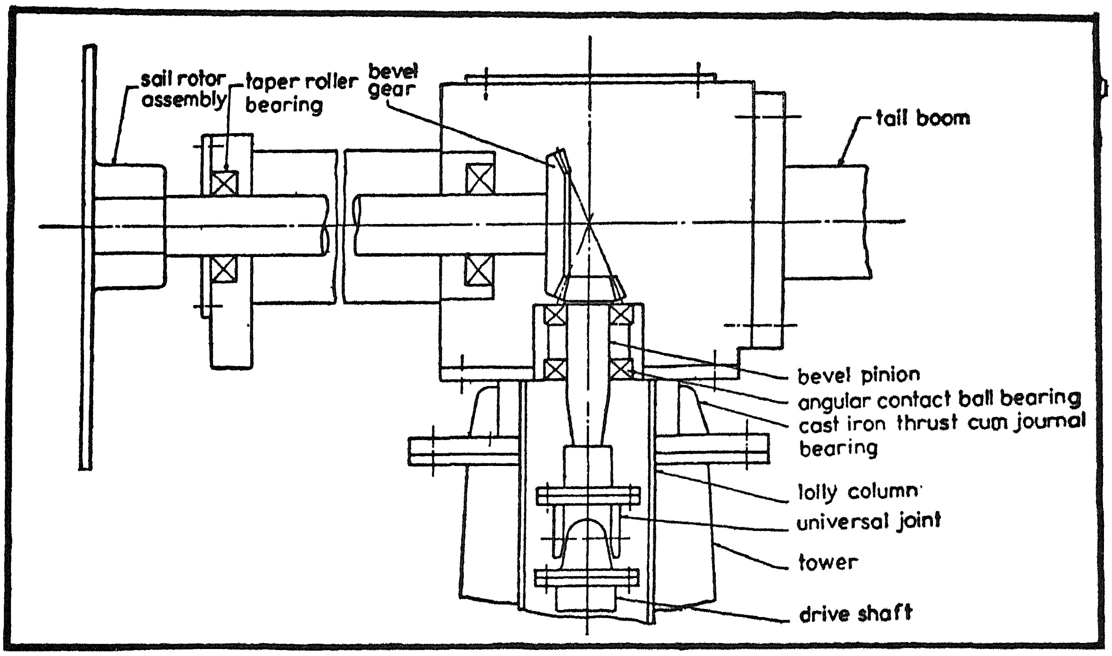


Fig. 41: Head Mechanism Assembly

The gear box housing is fabricated by suitable welding steel plates and channel sections. Bearings, seatings in the house are also provided by welding thick steel plates. The pinion of the bevel gear pair is supported using a pair of angular contact ball bearings, and the bearing house is bolted to the gearbox casing. The gears and bearing are lubricated by grease.

A lolly column pipe of 110 mm outer diameter and the whole assembly is supported using 2 cast-iron bearings which allow orientation of the rotor in the direction of wind.

The output shaft is brought down using steel pipe shafting connected with a flexible coupling and a universal joint. The vertical output shaft is guided using number of self-lubricating, wooden bearings at about 2 m intervals.

The bottom of the output shaft is connected to a bevel gear-box which again turns the axis of rotation by 90°. The horizontal output shaft of the lower gearbox is connected to the pump shaft through a flexible coupling. In a recent arrangement two pumps were mounted with their shafts in vertical plane. The drive is provided by means of roller chains and sprockets replacing the lower gearbox.

Pump :

A commercially available swinging vane rotary pump is used with the windmill (Fig. 14). The pump has three gun-metal vanes which swing about their hinges on the pump rotor as shown in the Figure. The pump is mounted eccentrically within the stator body. The effectiveness of pumping action depends upon the contact pressure between the swinging vane and the stator body. By using this pump, it has been possible for the windmill to start at windspeeds of 7 km/hr, yet keeping a low solidity of 25% on the rotor.

Tower :

The tower which stands 12 m in height is a combination of a free standing tapered tower (portion above wire ropes) and guyed tower (below wire ropes).

Braking :

A mechanical manually operated band brake is provided on the vertical shaft at the platform level. It is used for stopping the rotor in order to facilitate furling of the sails.

Operating Data :

Rotor diameter : 10 m
Solidity ratio : 0.48
Tip-speed ratio : 2.9 @ 7.22 kmph windspeed.
Cut-in-windspeed · 7 kmph
Pump : Swinging vane rotary pump mounted on the tower at 6 m above ground level
Suction head : 6.85 m
Discharge : 6000-11,000 lph @ 10-16 kmph windspeed.
System efficiency : 11% at 7-12 kmph windspeed.

Conclusion :

The windmill has been designed and tested as a prototype. Based on this experience, modifications have been suggested, including simplification of the top gear box, automatic regulation of the system, a shorter tower, and a suitable pump for replacing the two pumps originally meant for oil pumping.

References :

1. A Horizontal Sail Windmill for Use in Irrigation by S.K. Tewari and others. Bangalore, National Aeronautical Laboratory, March 1979. 19p. (NAL-TN-54).

2. Economics of Wind Energy Use for Irrigation in India by S.K. Tewari. Science, V.202, 4367, Nov.3, 1978. p.481-6.

NAL-MP-1

Institutional Affiliation :

National Aeronautical Lab.,
Post Bag No. 1779,
Bangalore 560 017,
INDIA.

Background :

A new multipurpose windmill called MP-1 has been recently designed and developed.

Application :

Presently it is intended to be used for pumping water from shallow wells where water table is not deeper than 7 m from ground level. The design has good potential for use other than water pumping.

Suitability :

The pump is well matched for moderately windy areas.

Type :

Horizontal axis, sailwing windmill device.

Design Features :

Rotor Assembly : (Fig. 42)

Rotor assembly is a simple construction from steel tubes, thin wire shapes and canvas sails. The rotor diameter is 7.5 m.

Sail Assembly :

Six triangular sails with maximum width of 1.5 m have been optimised for moderate windspeeds. Sails are curved and aerodynamically efficient. Elastic members and twisted wire loops included act as 'fuses' for safety of sail rotors in gales and storms. Arrangement of this type also avoids sail fluttering.

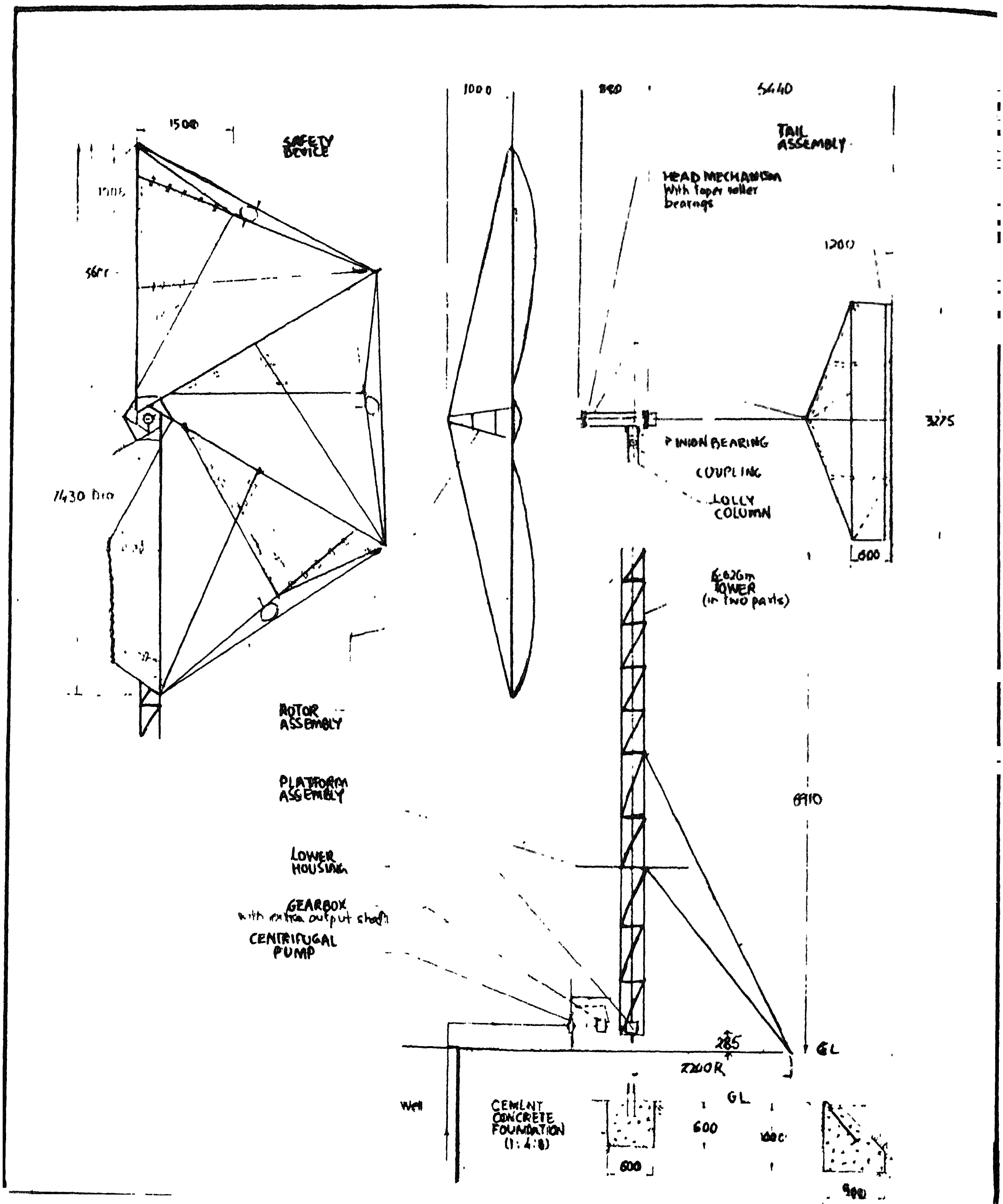


Fig. 42: Schematic View of MP-1 with Sub-Assemblies Seperated Out

Power Transmission :

The windmill consists of three sub assemblies :

- a top housing which carries tapered roller bearings to absorb thrust loads and a bevel gear-set to transmit rotor shaft power to a vertical drive shaft. This sub assembly also functions as the turntable to suit changes in in wind direction which is also assisted by a tail vane.
- lower housing which supports the weight of the drive shaft and once again makes the shaft axis horizontal.
- the step-up gear box is used to provide 1500 rpm at the rated windspeed.

Pump :

A 1.5 Hp centrifugal pump is used having suction line diameter of 50 mm. The problem of drap in efficiency of a centrifugal pump if operated under and above the rated speed has been taken care of through an optimal matching for speeds falling in the most useful range of 3-6 m/s (10-20 kmph).

Braking :

The structure is designed to withstand windspeeds of 120 Kmph with brakes applied. Rotor can be stopped with brakes applied. Rotor can be stopped with the help of a hand brake provided at the ground level. The sail can also be manually furled when windmill is not in use.

Tower :

The tower is guyed, built-up lattice column which is convenient for installation and appropriate for supporting a vertical drive shaft.

Operating Data :

Cut-in-windspeed: 9 Kmph
Discharge : 15000 liters ph @ 18 Kmph
Head : 7 m

Performance :

Annual or Monthly Mean Wind Speed	Million liters during a month	whole year
3 Km/hr	0.1	4.0
6 Km/hr	0.7	14.0
10 Km/hr	2.8	29.0
12 Km/hr	3.7	38.0
17 Km/hr	6.2	70.0
20 Km/hr	7.8	
25 Km/hr	10.3	

Conclusion :

The windmill is of modular design of three mass producible sub assemblies, namely top and lower housings and a step-up gear box. The tower, rotor, tail vane and drive shaft can be fabricated in any small workshop having welding facilities.

Reference :

1. MP - 1: A Multipurpose Windmill by National Aeronautical Lab., Bangalore. (Brochure)

SWD CRETAN WINDMILL

Institutional Affiliation :

Steering Committee for Wind Energy
in Developing Countries (SWD),
P.O. Box 85, Amerfoort,
THE NETHERLANDS.

Background :

SWD promotes and organises research and development of wind-powered equipment suitable for application in developing countries. The Cretan windmill (prototype) described here is one example.

Type :

Horizontal axis, sail-wing device (Fig. 43).

Design Features :

Rotor Assembly :

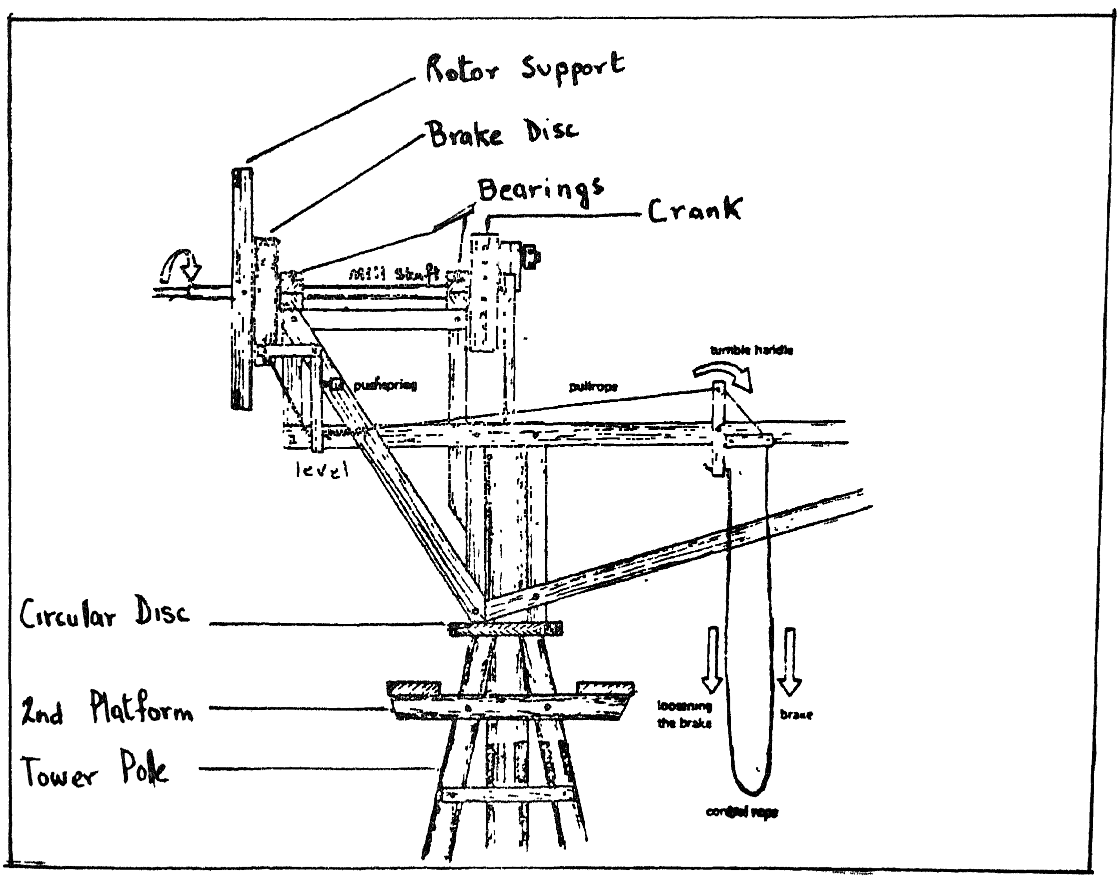


Fig. 44: The Head Construction

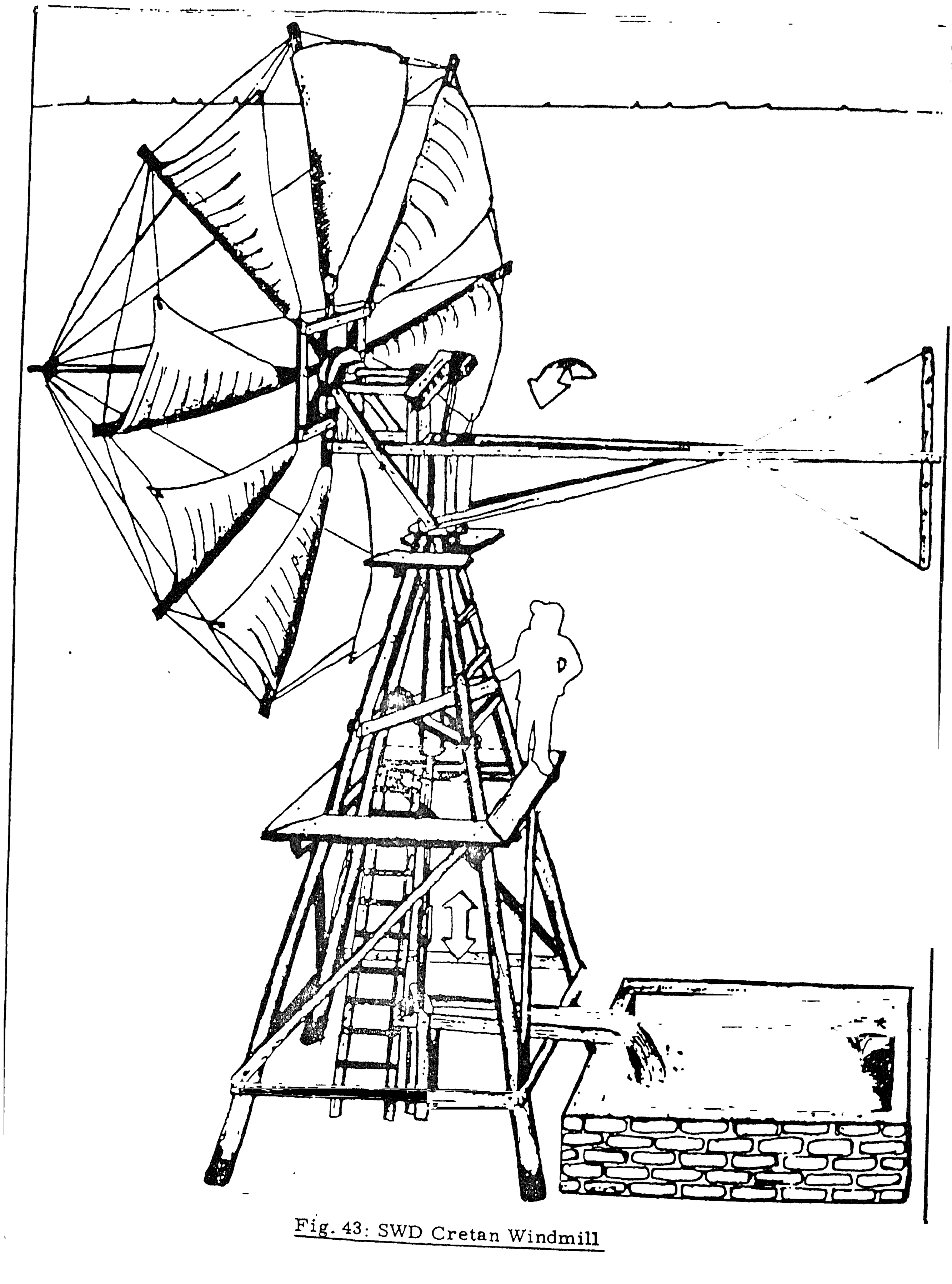


Fig. 43: SWD Cretan Windmill

The rotor consists of :

- a shaft made of steel pipe (50 mm dia. and 3.5 m length) which passes through a wooden rotor support 600 - 600 mm in size is shown in Fig. 44. The rotor shaft must reach out 2.50 m in front of the support frame for guying the rotor frame. The front shaft is necessary for reason of rigidity of the rotor. If a long shaft is not available then another, less thick and smaller pipe can be inserted into the rotor shaft as in Fig. 43.
- 8 sail poles (40x50; length 3.20 cm) are fastened to the rotor support as shown in Fig. 44.
- Guy wires are ties from the end of the poles to the mooring point such that the poles are bent up by about 300 mm (Fig. 46)
- a 20 m rope is fastened from the tip of one pole to another, thus forming a regular eight-sided figure.

Sail Assembly :

8 triangular sails made of plasticided canvas are fastened to the poles by lacing with guying ropes. On the longest side of the sail, round holes are cut and reinforced with sail rings. The sail is rigged in such a way that it passes behind the rotor poles towards the next pole. The flap at the front smooths out the air stream, allowing a sort of aerodynamic profile.

Power Transmission :

The rotary movement of the windmill shaft is converted into reciprocating motion by means of an adjustable crank.

The crank (made of 2 pieces of wood 55 x 110 x 400 mm), the connecting rod (wood, 30 x 30 x 600 mm) the cross-head (2 pieces of wood 110 x 30 x 400 mm) and piston rod (25 x 50 mm and length as long as necessary) are all connected as shown in Fig. 47.

Pump :

The piston pump used consists of a 5 m long plastic pipe of 125 mm inner diameter. The lower end of the pipe has a coarse perforation and rests on the gravel. (Fig. 48) The lower end of the pipe is stopped with a wooden disc or a plastic cover, fastened around the pipe with iron wire.

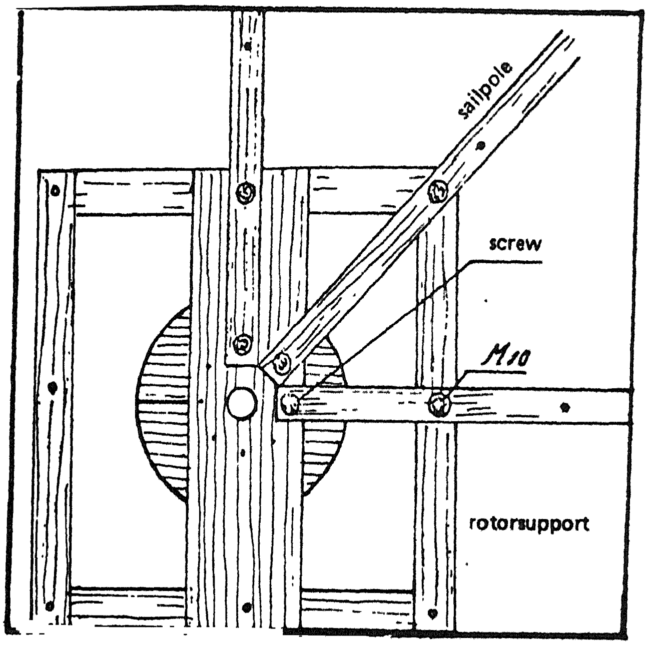


Fig. 45: The Rotor Support and Sail Pole

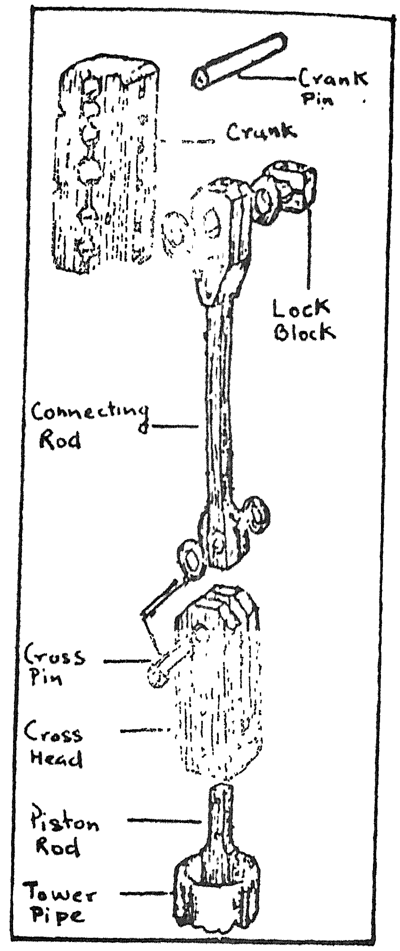
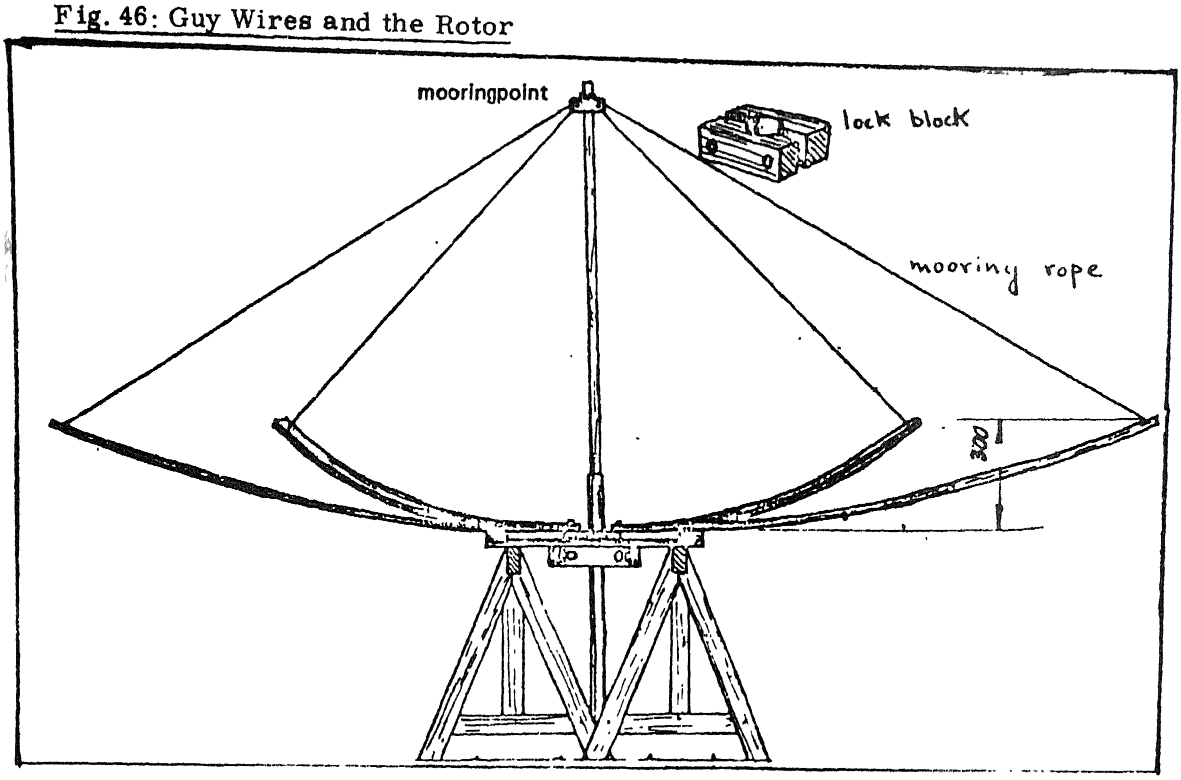


Fig. 47: Wooden Transmission

Fig. 46: Guy Wires and the Rotor



The piston pump assembly is shown in Fig. 49. Both piston and foot valve are made of eight-holed circular wooden pieces with an additional central hole to fit the leather or rubber valve mounted on it. Leather sealing is wound around the piston and further tightened by iron wire. The foot valve is located 40 cm above the lower-end.

The pump cylinder rises about 1 m above the surface and is cut off at an angle to discharge the pumped water in the desired direction. A gutter carries the water to a storage tank.

Tower :

The tower is made out of 4 pine poles (7 m long and dia. 8 to 15 cm); 4 semi-round logs (3 m long) and a steel pipe (150 mm external dia.) firmly secured in place. Four heavy wooden boards (30 x 20, length = .8 m) form the second platform. Wooden planks nailed to the sides serve as steps.

Foundation :

For foundation 4 holes 60 x 60 x 90 cm for the tower legs are dug. Each hole is provided with a floor of stones on which the tower legs rest. The holes are then filled with a mixture of sand and water.

Braking :

The brake system comprises of a wooden brake disk mounted on the mill shaft. A steel band passes over this disc, and is connected to the pull-rope by a system of levers (see Fig. 44). When one side of the rope is pulled, the tumble handle turns clockwise and actuates the bell crank which pulls the steel band tightly over the brake disc and brings the rotor to a halt.

Operating Data :

Rotor diameter : 6 m.
Pump : Piston Pump (PVC cylinder perforated at lower end, 5 m height, 125 mm inner dia. Foot-valve and piston made of wood).
Bore hole : 200 mm dia. 4. 5 m depth.
Discharge : 6000 lph.

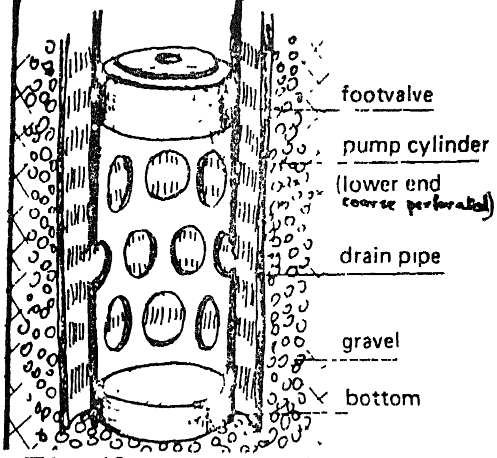
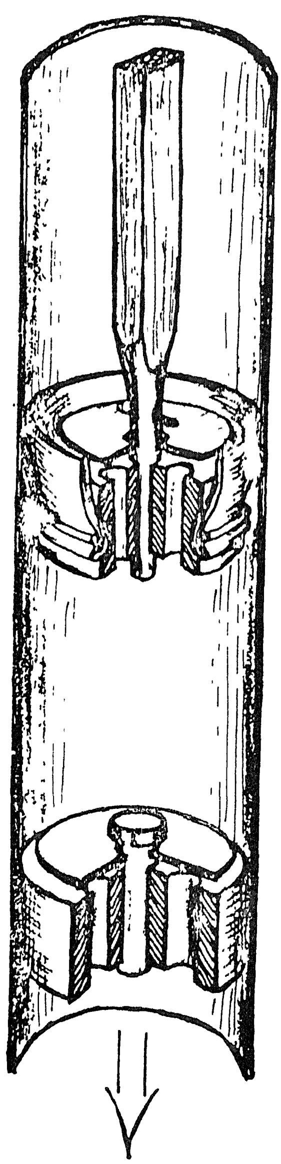


Fig. 48: Lower End of Pump Cylinder



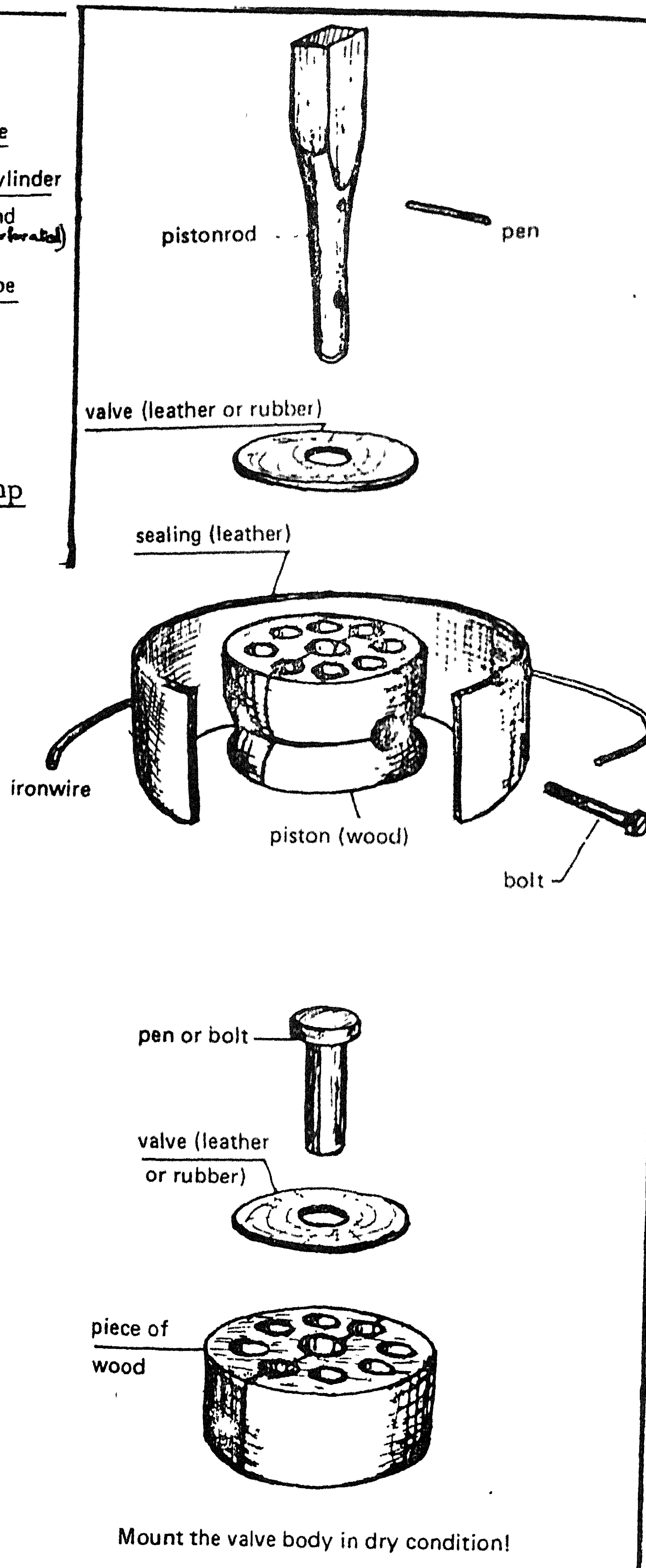


Fig. 49: Simple Piston Pump

Conclusion :

The design is based on the possibility of constructing the windmill using materials normally available at the village level (logs, rugged sawn wood, piping, etc.). Even the tools used are manual tools (chisels, handsaws, etc.). The unit described above is a prototype and it is not known whether the design is patented. The SWD is likely to be liberal in giving permission to use the design.

Reference :

1. Construction Manual for A Cretan Windmill by N. van de Van. Amersfoort, Steering Committee for Wind Energy in Developing Countries. 1977. 59p.

CYCLO WINDMILL

Designer :

VITA Peace Corps Volunteer.

Institutional Affiliation :

Volunteers in Technical Assistance,
3706 Rhode Island Avenue,
Mt. Rainier, Maryland 20822,
U.S.A.

Background :

This windmill designed and constructed in 1968 at Santa Barbara, Philippines, is a structurally improved version of a design fabricated earlier in 1963. The unit is also known as the Santa Barbara Windmill.

Applications :

Can be used for continuous pumping from a well or to pump water from a river to a given site.

Type :

Horizontal axis, helical sail-wing device. (Fig. 50)

Suitability :

Most suitable for areas prone to strong unidirectional winds.

Design Features :

Rotor Assembly : (See Figs. 51 & 52)

The rotor unit comprises of an axle shaft (2.5 cm diameter cold-rolled steel rod; 244 cm long) on to which 5 angle iron pieces are welded (2.5 cm x 61 cm long). The first angle iron is kept perpendicular to the shaft and welded at its centre, 35 cms from the one end of the shaft with the open side of 'V' towards the axle. Each following angle iron is welded at 45^{0} counter-clockwise w.r.t. the preceding one and spaced 43 cm apart on the axle.

Five steel rods (1.25 cm dia.; 61 cm length) are placed on the other side of the axle, each facing an angle iron. These rods are welded at the centre to the axle as well as to the angle irons at their ends.

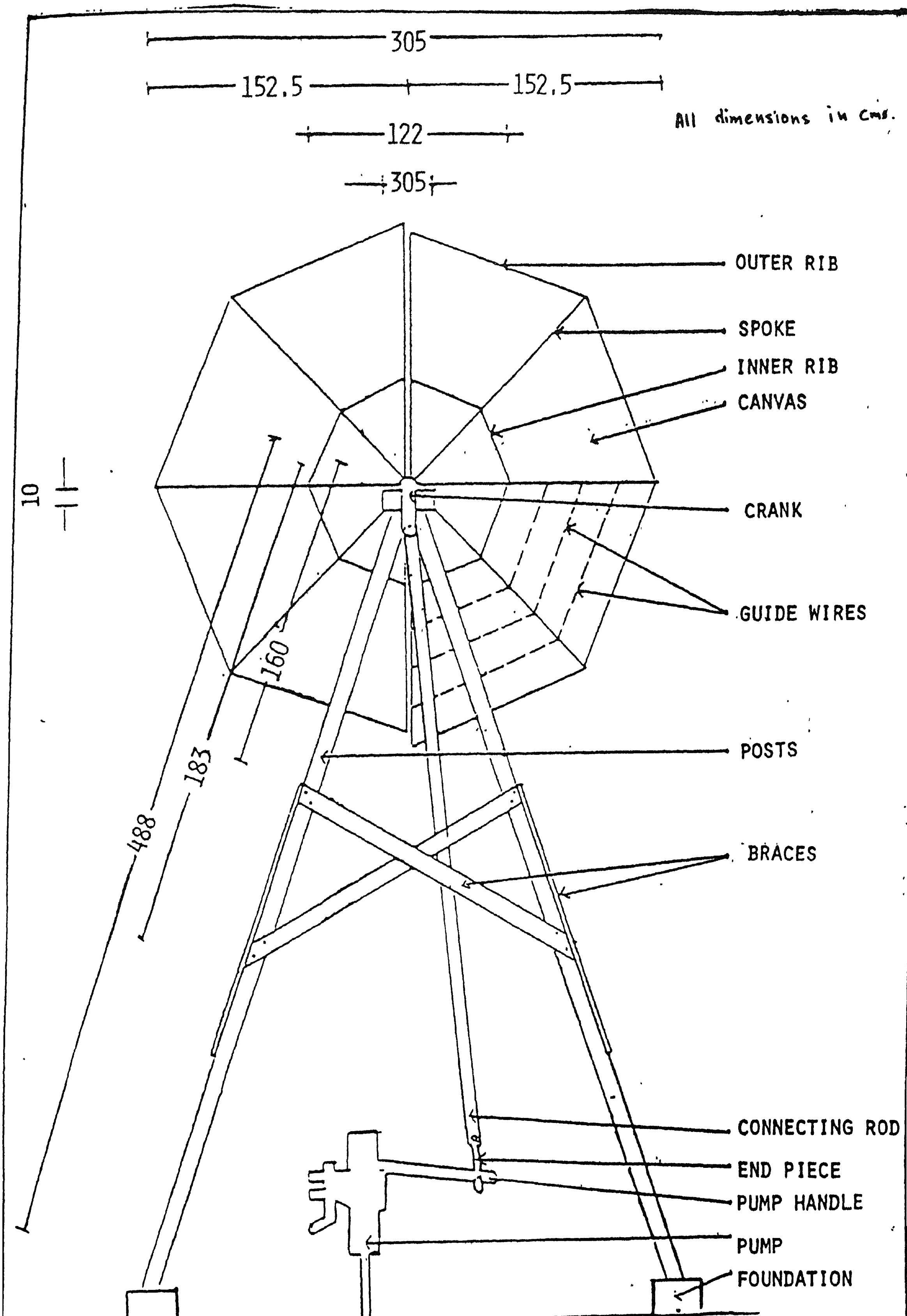


Fig. 50: Helical Sail Windmill - Front View

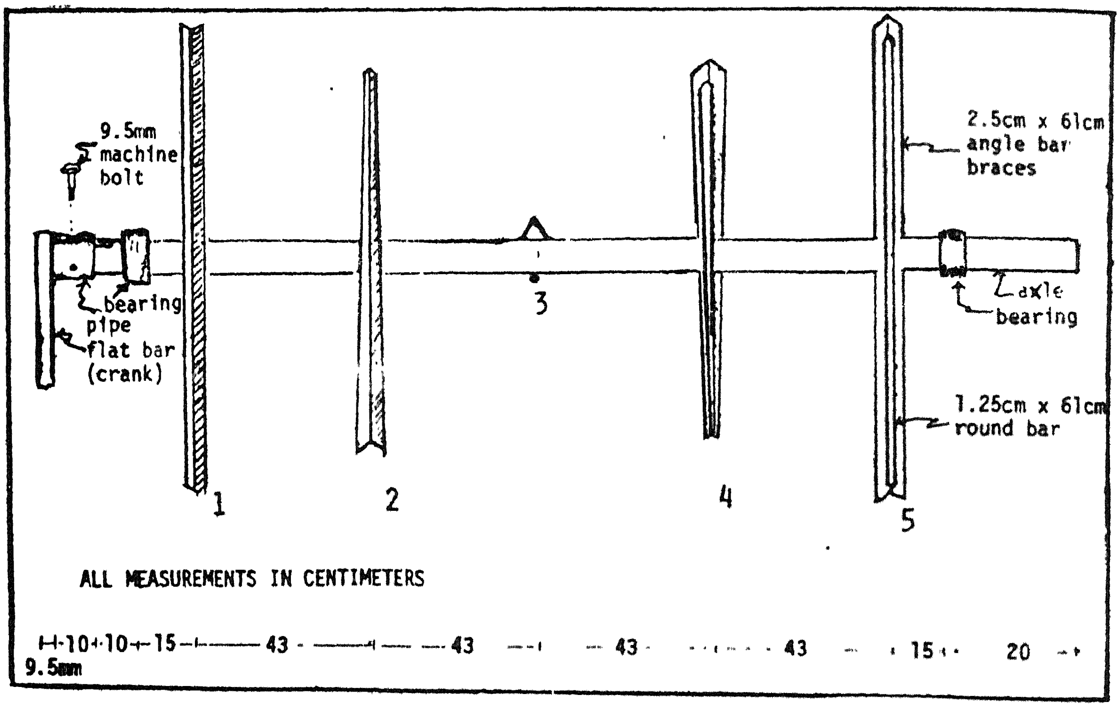


Fig. 51: The Axle Shaft

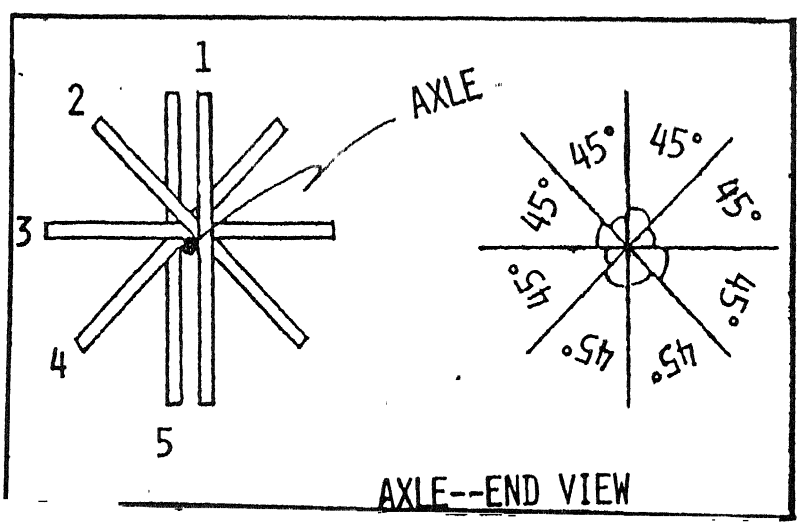


Fig. 52: Axle-Fnd View

The shaft rotates on two bearings placed at some distance from each end.

Spokes : (See Fig. 53)

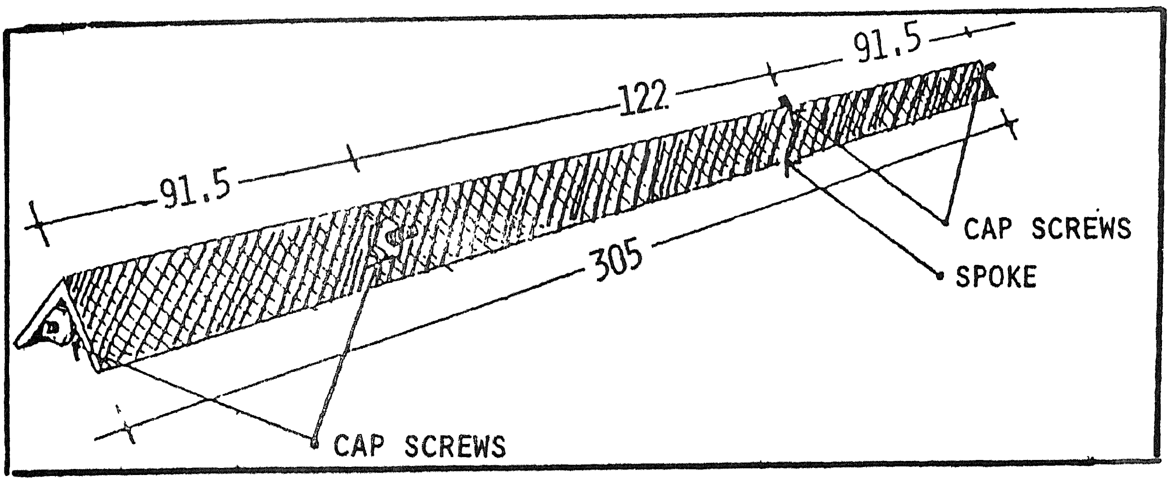


Fig. 53: The Spoke

Five angle irons (2.5 cm x 305 cms long) which form the spokes are fixed to the angle welded to the shaft by means of "U" bolts. The spokes have four cap-screws, two welded at the end faces and two welded on to the outer side faces 91.5 cm from the ends.

Ribs :

A 6.5 mm dia. steel bar is cut into sixteen pieces, eight of 124.5 cms length and eight 64 cms length. They are bent at their ends to form loops. The longer bars are connected between the extreme cap-screws of the spokes so as to form outer ribs and the shorter bars to the inner cap screws on the spokes to form "inner ribs."

Tension wires :

18 gauge wires are connected to the extreme ties of the spokes each passing through the central spoke to form tension supports.

Sail Assembly : (See Fig. 54)

The sails, 8 in number, are made of heavy canvas and are trapezoidal in shape. A rope is sewn into the seams to make the sails stronger. Curtain rings attached to grommets help in securing the sails to the spokes and ribs. The canvas is coated with paint or suitable material for ensuring a longer life. Guide wires (16 gauge) are placed across the face of the canvas to support it and act as a wind-brace.

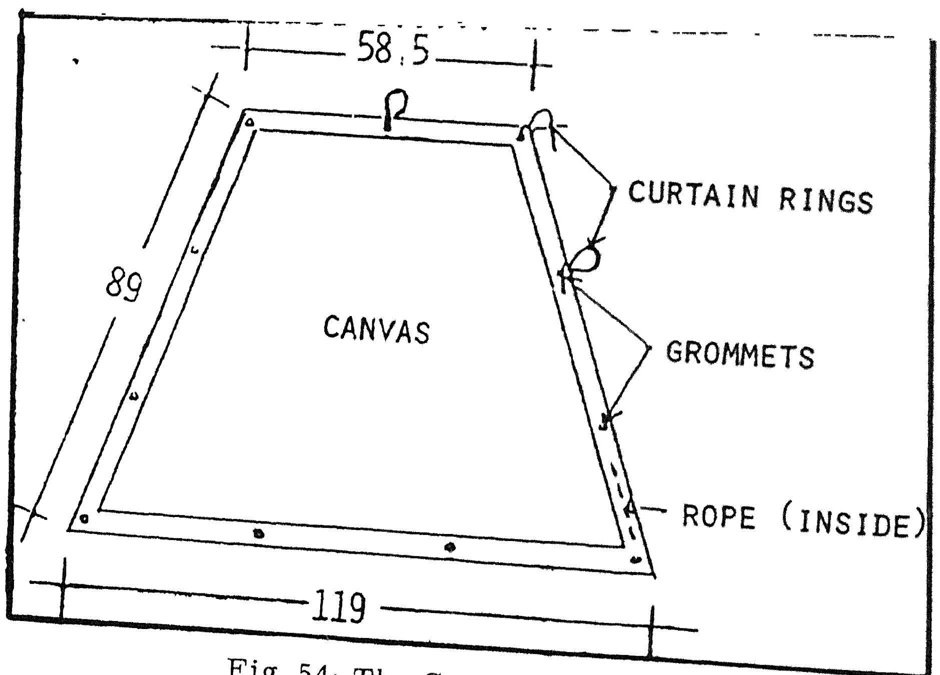


Fig. 54: The Canvas Sail

Power Transmission :

A flat bar welded to a short pipe at right angles to it and mounted at the rear end of the axle acts as a crank and converts the rotary motion of the axle to up-and-down motion via a connecting rod fitted to the handle of a reciprocating pump.

Pump :

The windmill makes use of a commercially available self-priming, double-action piston pump. Fig. 50 shows how the pump handle is attached to the connecting rod assembly. Two or three 9.5 cm holes are drilled in the pump handle. Holes drilled closer to the pump give more water per stroke but fewer strokes, holes taken further sway give less water per stroke but more strokes.

Tower :

The tower comprises of two 'A' frames made from wood posts (7.5 cm x 10 cm x 475.5 cm length) with two wooden braces on each side (2.5 x 10 x 213.5 cms). Wooden blocks with suitable recesses are mounted on the top of the frames to form the bearing blocks. The total tower height is 488 cms.

Foundation :

Four concrete blocks forming a square of 30.5 cm sides act as a foundation for the structure.

Operating Data :

Rotor diameter : 3 metres (approx).
Pump : Self-priming double-action piston pump.
Discharge : 1848-2496 lph.

Conclusion :

The design appears very rugged and can be constructed in areas where hardware and welding facilities are available. The windmill is available for sale as a complete kit with all component parts, including a shallow well pump and foot valve, except for water piping and wood parts for the tower. Information as to whether the design is patented is not known.

Reference :

1. Helical Sail Windmill. Mt. Rainier, Volunteers in Technical Assistance, Inc., 1979. 50p.

GAUDGAON WINDMILL

Contact :

William W. Smith.

Institutional Affiliation :

Shri Shivaji Shiksan Prasarak Mandal (SSSPM),
Gaudgaon 413 406
Taluka Barsi,
Sholapur, Maharashtra,
INDIA.

Background :

In 1977, VITA (Volunteers in Technical Assistance) started the Gaudgaon windmill demonstration project in Sholapur District with SSSPM as its counterpart. Three different windmill designs were tested having rotor diameter 5 m, 7.5 m and 10 m. The 7.5 m rotor diameter windmill is described here.

Type :

Cretan type, sail wing device.

Application :

Pumping water for irrigation.

Design Features :

Rotor Assembly :

The rotor of 7.5 m diameter consists of :

- a rotor hub made of hardwood with two clamps of steel flat around its circumference. It consists of a square hole to fit the main shaft and eight slightly tapered square holes to take the bamboo rotor arms.
- a rotor ring which is bolted to the eight bamboos to hold them in place.
- a circumferential wire of galv. steel which connects the tips of the bamboo. Each bamboo is further braced with two other wires. One wire to the front of the main shaft and one attached to the welded tabs near the forward main bearing. Thus, the rotor arms are braced to take wind from either front or the rear.

main shaft of galvanized pipe runs in hardwood bearings. It extends (6'2") beyond the forward bearing. 4 pieces of angle iron (8") long are welded to the main shaft to form a box section where the rotor hub is located. Main shaft is also drilled at the forward end to attach the 16 rotor side support wires.

Sail Assembly :

Eight triangular sails are made of either thick canvas or thin cloth. The trailing edge is kept parallel to the weave of the cloth, enabling the sail to stretch near the leading edge while it remains taut at the trailing edge. A sleeve is sewn into the leading edge of the sail to accept the sail bamboo. Alternatively the sails may be fitted on the punka bamboo. Large button holes attach the lashings on the leading edge of the sail. At the trailing corner, a loop of card is sewn to the sail to accept the sheet rope.

Chassis :

The chassis is made of angle iron. The two chassis side members are bent to the sam e shape as the tower head ring. Cross members hold the side members together and provide mounting places for the main bearings and lift arrestors. The rear ends of the chassis side members are bent and twisted so that they support the tail area of (3") pipe. Two steel wires lead from the tail arm to the ground to allow the windmill chassis to be turned to face the wind. A truss prevents the tail arm from bending towards the grounds when wires are pulled.

Pump :

The piston pump uses a square pump cylinder made from 4 teak wood planks clamped together. Pump cylinder is made of brass or PVC plastic pipe. Maximum pump stroke is (22"). The cylinder is (32") long. Wooden end plates are held against the top and bottom of the cylinder by 4 tie bolts. Commercial cast iron pipe flanges bolt to the end plates for attaching the suction and discharge pipes. A flexible suction pipe is used below the pump, with a commercial leather flap-type foot valve fitted at the bottom of the suction pipe.

Pump piston is fabricated from wood and metal with a leather washer and either a leather flap-valve or a ball valve. The piston is mounted on a cut away pipe flange for attaching to the pump rod. A pump rod guide plate is fitted between the upper end plate and flange to prevent the piston from running off center and scaring the side of the pump cylinder.

Pump rod of galv. pipe runs inside the galv. delivery pipe. The top of the pump rod is bolted to the pump lever.

Pump Lever :

Pump lever is (10'6") long and made of two angles welded together to form a box section. The two ends of the pump lever are forged parallel and drilled to accept the pump rod and lower connecting rod.

The lever is slightly longer on one end than the other. The end of the lever opposite the pumprod is fitted with a counter weight. The lower connecting rod is connected to the pump lever on the bottom and the traveller of the variable stroke lever at the top. The variable stroke lever is fitted inside the tower just above the sail access platform. A chain linkage with a pulley at either end of the lever allows the traveller to be moved back and forth along the lever. The upper connecting rod is fitted with a swivel so that the windmill can turn without the rod being twisted. The top of the upper connecting rod has a welded "T" fitting to accept the wooden connecting rod bearing which fits on the crankshaft.

Tower :

Tower is (32') in height and made of mild steel angle iron. Consists of horizontal bracings, X bracing and interior bracings. Tower height can be extended to (80').

Platform :

The tower is fitted with a sail access platform about (13') below the windmill main shaft. The platform extends around all 4 sides of the tower and is made of wooden planks supported on angle iron. A ladder is built into one side of the tower.

Operating Data :

Performance :

Power output (in HP) at different windspeeds

Windmill diameter	5 mph	10 mph	15 mph	30 mph
7.5 m (24')	.033 HP	.18 HP	.90 HP	7.4 HP

Note: 1 HP gives the ability to pump 1065 ft^3 per hour from a 30 ft head

Conclusion :

The simplicity of the windmill design, enables it to be fabricated and repaired by village workers, requiring mainly a blacksmith and a crapenter. The construction incorporates some welding, drilling and threading. It uses no tail and hence requires the operator to correctly face it into the wind. Because of the slow speed of rotation of the windmills ball bearings are not used.

Construction plans, blue prints are available from SSSPM. Also during 1981-82, with funding a windmill fabrication training course is being conducted at Gaudgaon to teach rural people the skills needed to build this type of windmill.

References :

1. Village built sailwing windmill handbook by William W. Smith III. 1981. 38p.

2. "Sholapur Windmills" by William W. Smith III. Vita News, Jan. 1981. p. 5 & 8.

SAHORES WINDMILL

Designer :

J. Sahores.

Institutional Affiliation :

World Council of Churches,
Commission on the Churches
Participation in Development,
150, Route de Ferney,
1211 Geneva 20,
SWITZERLAND.

Background :

The Sahores windmill was developed by a group of French engineers. This windmill incorporates the primary elements of the American multibladed windmill.

Application :

Pumping water from well.

Type :

Horizontal axis, multibladed sail windmill. (Fig. 55)

Suitability :

The counterweight system enables the operation of the windmill at windspeeds from 2 m/sec up to strong winds.

Design Features :

Rotor Assembly :

The 3 m diameter wheel is made of bamboo (or wood). The rotor assembly (Fig. 56) consists of :

- two wooden disks, 9 small disks of diameter 12.5 m nailed on to a bigger disk of diameter 40 cms to form a hub.
- 16 sail-beams radiating from the hub. Each beam is nailed at its end to the big disk and bound by rope along the circumference of the bigger disk.
- a hub extension which is placed slightly eccentric with respect to the hub. The extremities of each beam is attached to the end of the hub extension by means of a rope. (Fig. 57)

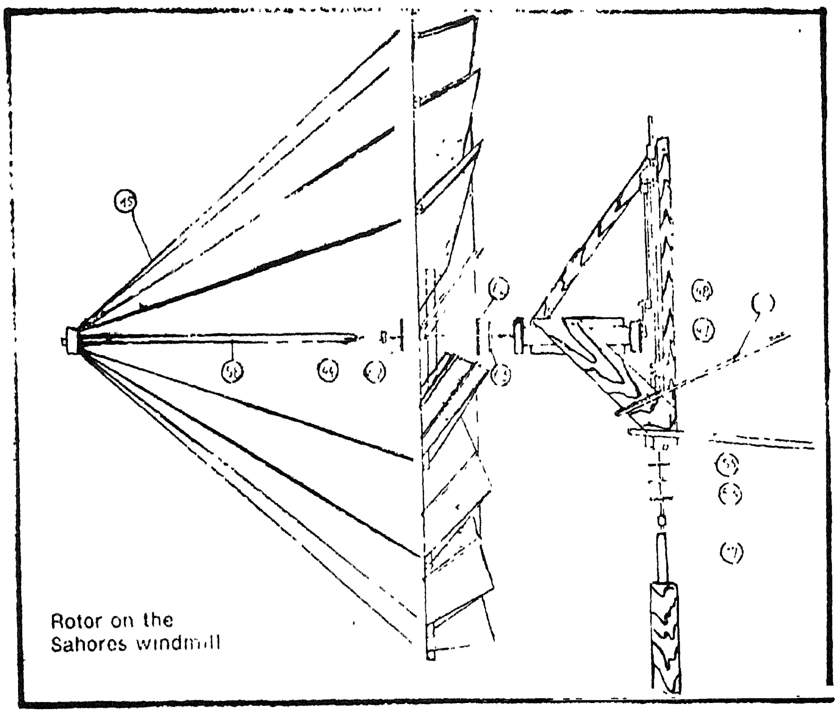


Fig. 55: Rotor on the Sahores Windmill

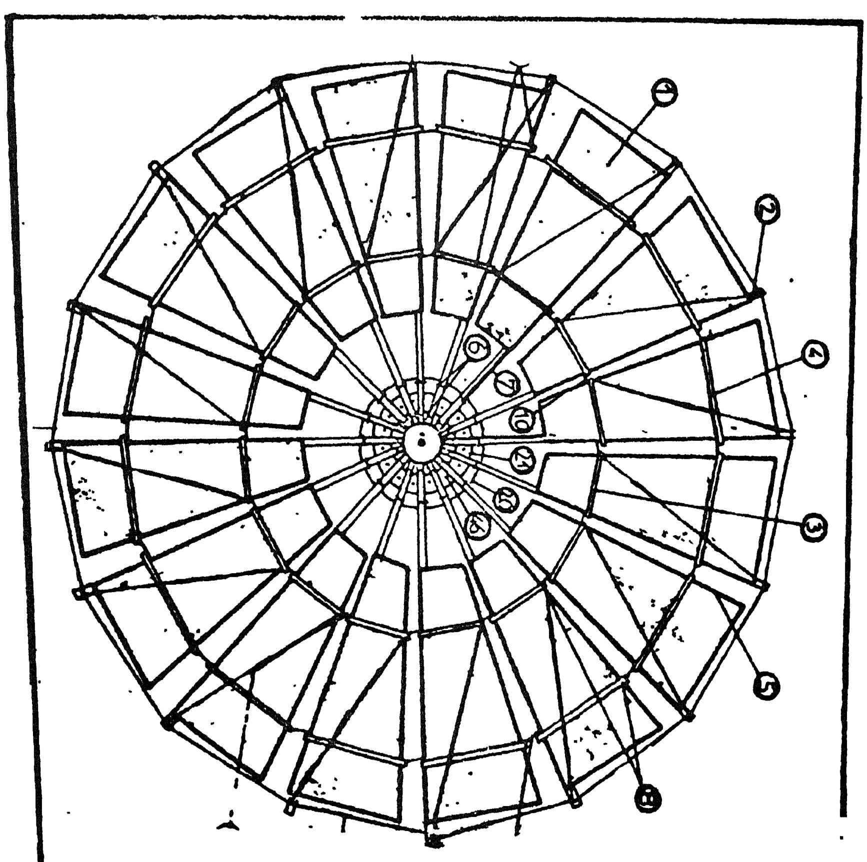


Fig. 56: Front and Side View of Rotor

As shown in Fig. 58 each cloth sail is slipped on to the sail beam and consists of the following ·

- a counterbrace tucked within the slant edge of the sail
- one small spar and another big spar tied in place by cords 25 cm and 30 cm long (See Fig. 58).

These sails are further bound to each other by ropes at the following places :

- at the extremities (by chord 90 cm long)
- at the level of big spars
- at the level of small spars.

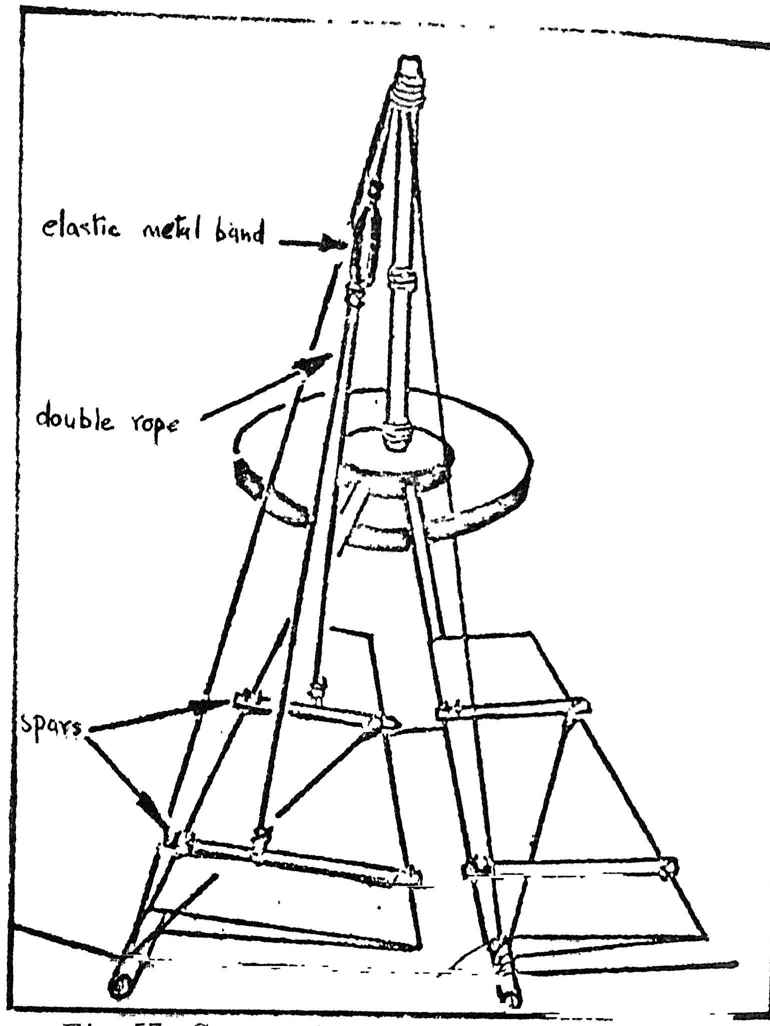


Fig. 57: Connections with Hub Extension

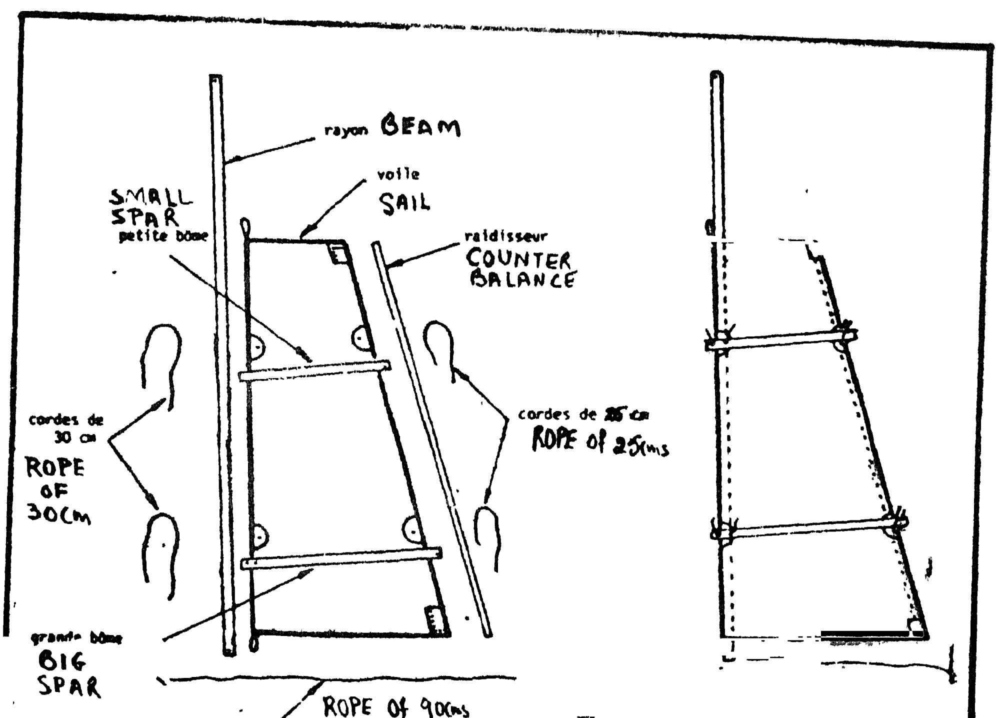


Fig. 58· Blade Assembly

Feathering :

The automatic feathering system consists of pieces of inner tube attached so that the blades open more as the wind becomes stronger, thus protecting the windmill from damage.

Power Transmission :

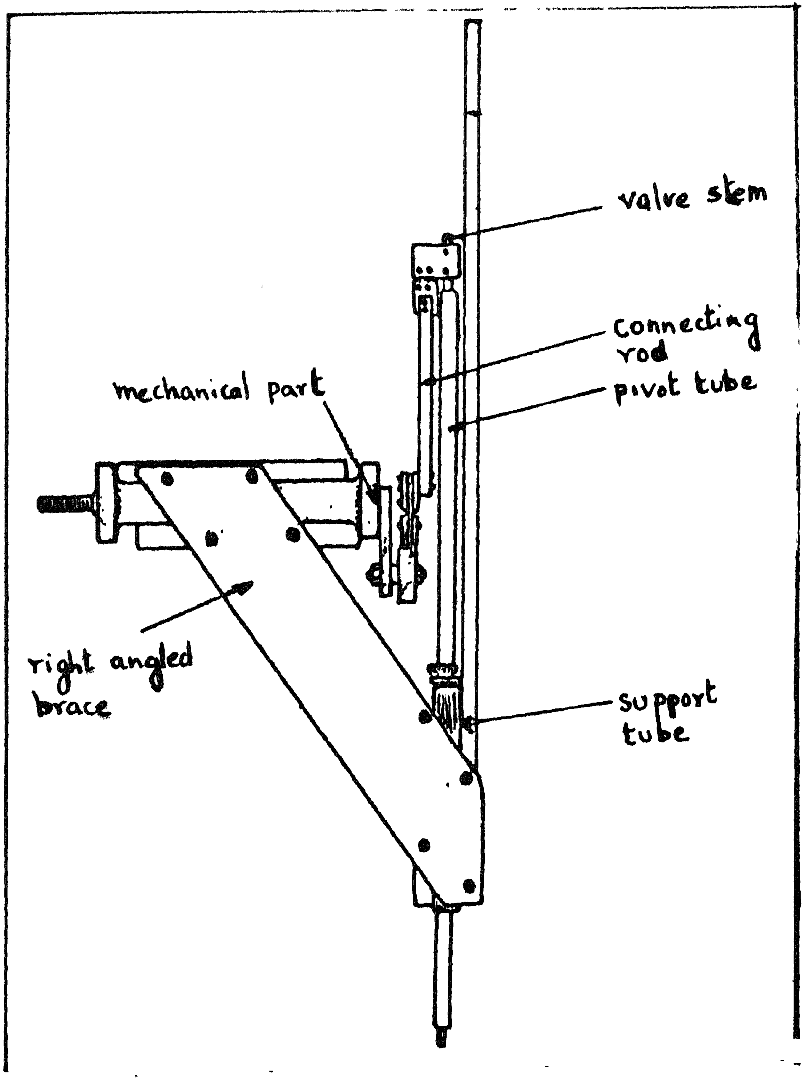


Fig. 59 Mechanical Part and Connecting Rod

As shown in Fig. 55 and Fig. 59 the transmission consists of a crank, connecting rod, valve system, bamboo rod, the counter-weight system and the balancer. The right-angled braces, support pipe wooden block and bolts are used to ensure a rigid assembly.

Tail Vane :

The tail (Fig. 60) helps to direct the windmill in such a way that the rotor always faces the wind. The tail assembly consists of :

- tail support by means of ropes
- wind bracing by means of cross-bars.

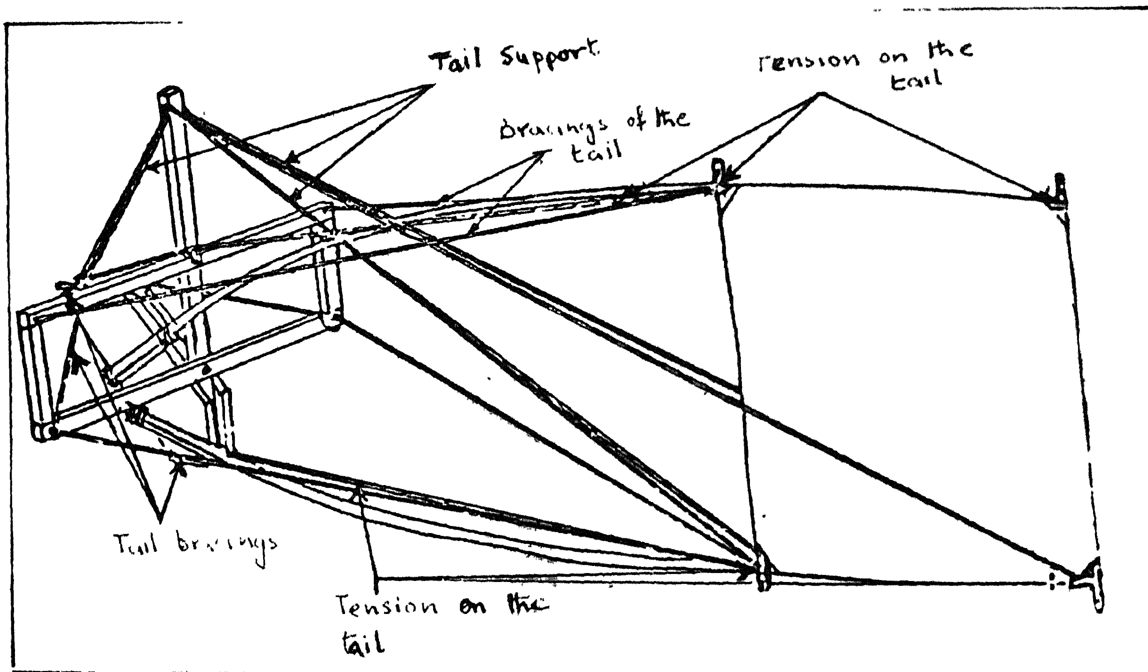


Fig. 60· Tail Vane Assembly

Counterbalance :

The counterweight system enables the pumping action to be adjusted by the owner, for operation at windspeeds from 2 m/sec up to strong wind.

Pump ·

The pump connection to the transmission system is shown in Fig. 61. The pump is a standard piston pump.

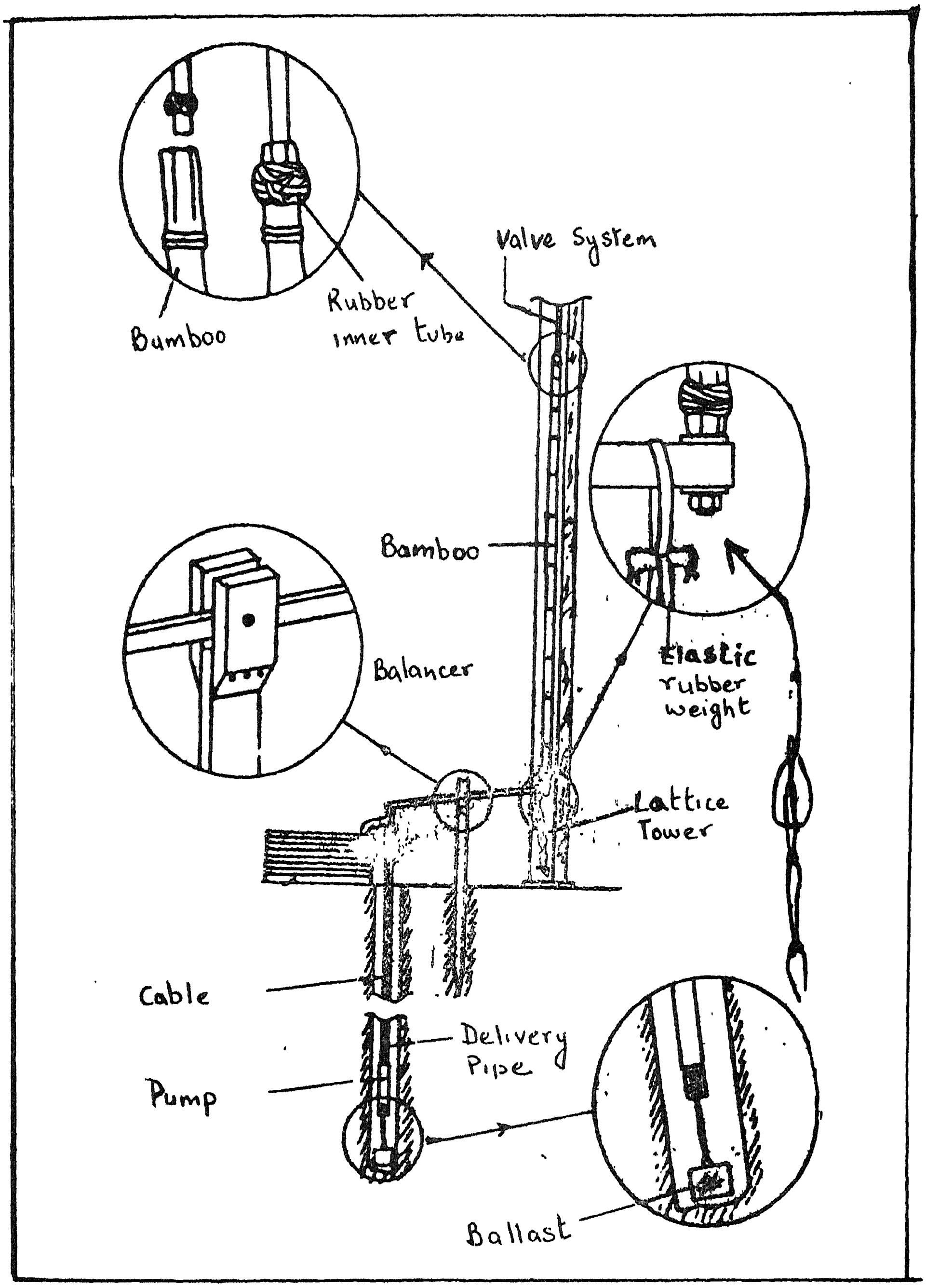


Fig. 61· Pump Connection

Tower :

The tower is in the form of a pole with 4 cord or steel guy wires for support.

Conclusion :

The windmill is light, simple and mainly uses bamboo sticks, cloth and strings. Only, welded transmission mechanism

needs some sophistication for manufacture. The first prototypes worked successfully for 3 years. 20 of these machines were built in 1974-75 and were also tested in Africa.

Plan and building process of the windmill are available in French from World Council of Churches.

Reference :

1. Sahores Windmill Pump by J. Sahores. Commission on the Churches Participation in Development, World Council of Churches, Switzerland, 1975. 80p.

THAI WOODEN BLADE WINDMILLS

Institutional Affiliation :

National Energy Administration,
Pibultham Villa,
Wind Energy Unit,
Kasatsuk Bridge,
Bangkok 5,
THAILAND.

Background :

These windmills are successfully being operated in areas south-east of Bangkok, salt farms near Bang Pakang and in the Chao Phraya delta and paddy areas surrounding Chachoengsao.

Applications :

These windmills are being used for the following applications :

- water pumping in coastal provinces
- lifting brine at salt farms
- water lifting for rice irrigation in the delta region.

Type :

Horizontal axis, high-speed wooden rotor. (Fig. 62)

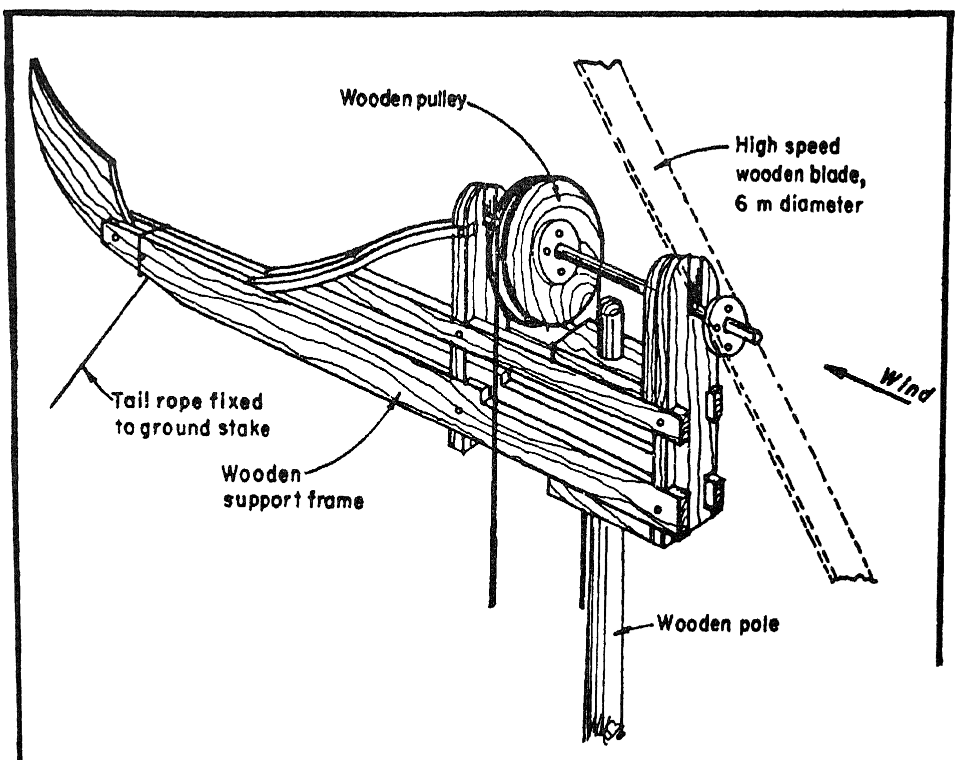


Fig. 62: Thai Water Pump Wooden Mounting Assembly

Design Features :

Rotor Assembly :

Each rotor is fastened in the centre by 4 bolts to a small steel plate hub welded to the end of a 3 cm diameter, 60 cm long steel main shaft. The steel main shaft rests in two steel ball bearings mounted in the front and rear vertical members of the wooden supporting frame. Older high-speed windmills utilize a 9 cm square wooden main shaft rounded at each end to turn directly on a wooden bearing surface. These high-speed rotors are characterized by high starting velocity, high rotational speed and low starting torque.

Blades :

The rotors consists of two or four wooden blades. Two blades are generally used near the coast with high winds, while four blades are used inland with lower windspeeds. Each pair of blades is carved from a single hardwood plank 8 m long, 20 cm wide and 5 cm thick so that it forms a crude but effective aerofoil, including same twist. In some places, 4 triangular cloth sails fitted to wooden spars are used to replace the high-speed rotor on this device so that the mechanism will operate in lower windspeeds.

Power Transmission :

Power is transferred by a twisted cowhide rope or steel chain from a 0.35 diameter wooden pulley attached to the shaft directly to a 1 m diameter wooden pulley on the lower shaft of the wooden-pallet chain pump. The cowhide rope or chain transmission can be twisted through 180° in response to changing wind direction.

Support Structure :

The vertical support is in the form of a wooden pole 25 cm in diameter and 5 m in height. The top and bottom planks of the horizontal support frame each have a round hole 10 cm in diameter to fit a short 10 cm diameter section cut at the top of the 25 cm diameter tower pole.

Operating Data :

Average windspeed	Head	Average discharge
21 km/hr	0.9 m	25.1/sec

Conclusion :

The windmill is made entirely of wood and can be locally constructed using ordinary carpentry skills and tools. These windmills are also manufactured upon order at a carpentry shop in Chacheongsao.

Detailed drawings of this type of windmill have been prepared by the Agricultural Engineering Division of the National Energy Administration.

Reference :

1. "Research, Development and Use of Wind Energy in Thailand" by the National Energy Administration (Thailand). Proceedings of the Meeting of the Expert Working Group on the Use of Solar and Wind Energy. Energy Resources Development Series No. 16 New York, UN 1976. p. 108-114.

DUTCH DESIGN
(Apoly-12-PU-500)

Institutional Affiliation :

TOOL-ORP Windmill Project,
Kusumih Kalan,
P.B. No. 62,
Ghazipur, U.P.
INDIA.

Institute of Engineering and Rural Technology (IERT),
(Allahabad Polytechnic),
Near Prayag Railway Station,
Allahabad 211 002, U.P.
INDIA.

Background :

With cooperation from TOOL Foundation in Netherlands, Organization of Rural Poor, Ghazipur developed prototypes of windmills 12 PU 500 and 12 PU 350 and since beginning of 1980 these windmills are being manufactured for commercial sale. Production Center of IERT (previously Allahabad Polytechnic) has plans to manufacture and install several hundreds of windmills in different parts of India.

Application :

The windmill can be employed for minor-irrigation, drinking water supply and brine pumping (in coastal areas) for salt production.

Type :

Horizontal-axis, Dutch type, metal bladed windmill. (Figs. 63 & 64)

Design Features :

Rotor Assembly :

The rotor frame consists of 6 spokes, an inner and outer wing which clamps around the 50 mm main shaft. Each of the B 12 blades of the rotor are fixed on to the blade supports, which provide the right curvature and twist.

Blades :

The blades are 12 in number made from 1.5 mm sheet iron having good aerodynamic qualities.

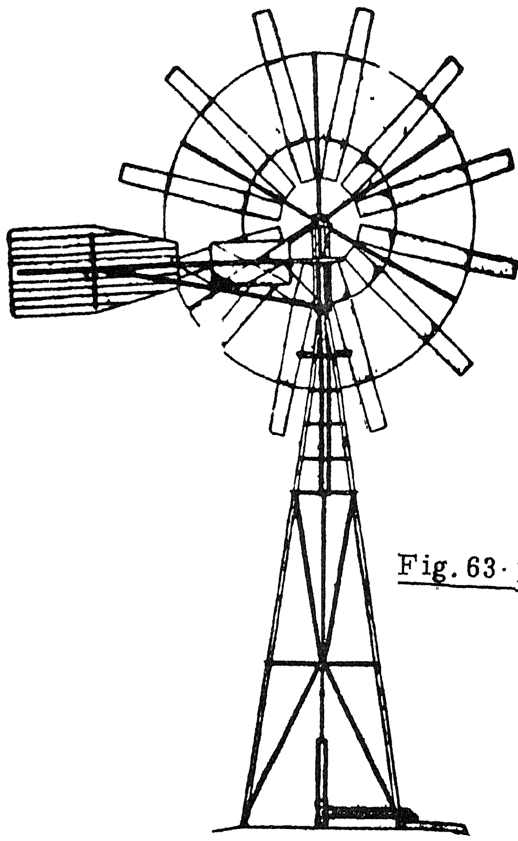


Fig. 63 · Dutch Design

Head Construction :

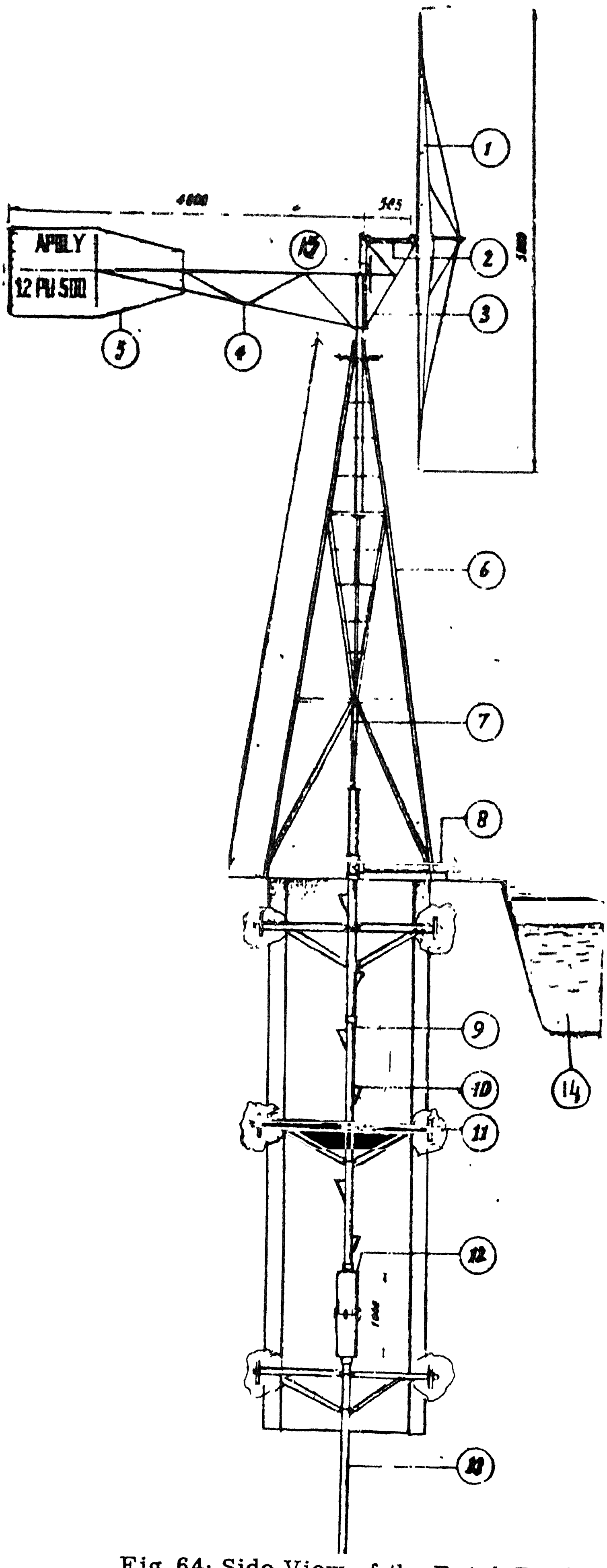
The head provides a rigid frame for the rotor and its shaft. An extended tail (4.0 m long) and vane steer the rotor in wind directions automatically. Basic materials for these are angle iron, some flat iron and 1 mm CR sheet (for the blades), bolts, nuts and springs.

Security Device :

An automatic security device unlocks the rotor from the main tail in case of high winds (10 m/s). The rotor turns 75° out of the wind direction and is thus protected.

Power Transmission :

The rotation of the main shaft is converted into reciprocating motion in order to drive the piston pump. The crank provides three possible crank positions by which the stroke of the pump can be changed. Basic material in the transmission are shaft, pillow-blocks crank, crank pin, connecting rod and wooden crosshead.



1	ROTOR
2	SHAFT
3	HEAD CONSTRUCTION
4	TAIL
5	TAIL VANE
6	TOWER
7	PUMP ROD
8	DISCHARGE PIPE
9	DELIVERY PIPE
10	STEPS
11	BRIDGE
12	PUMP
13	SUCTION PIPE
14	STORAGE TANK
15	HELP VANE SECURITY SYSTEM

Fig. 64: Side View of the Dutch Design

Pump :

A wooden piston slides in a steel cylinder actuating leather suction and pressure valves. Huge suction and pressure air chambers which have been integrated with the pump design, provide smooth functioning of the pump. The pump consists mainly of 2 mm M.S. sheet (air chambers) steel pipe, 10 cm socket and bolts and nuts.

Tower :

The standard tower is 6.5 m high and is fabricated out of 40 x 40 x 40 mm and 30 x 30 x 3 mm and some flats 30 x 6 mm and 100 mm dia tower pipe. The base dimension is 2.20 m^2.

Operating Data :

Rotor diameter : 5 m
Cut-in-speed : 2.5 m/sec to 3 m/sec
Cut-off-speed : 10 m/sec

Performance :

In standard performance (6.5 m high tower and 15 cm piston pump) it delivers the following water flows as a function of the windspeed at pumping head of 10 m.

Windspeed in m/s	Flow in l/s		
	120 mm	180 mm	240 mm
2.5	0.6	-	-
3.0	0.8	1.2	1.4
4.0	1.3	2.0	2.5
5.0	1.5	2.5	3.0
8.0	2.1	3.7	4.6
9.0	2.3	4.0	5.2
10.0	2.6	4.5	5.7

Conclusion :

With the support from the Dept. of Science and Technology, India, plans are to install 300 demonstration windmills and IERT has been given the task of manufacturing them. Brochures, manual and blueprints are available from IERT and ORP.

References :

1. APOLY-12 PU 500 - Water Pumping Windmill by Institute of Engineering and Rural Technology (IERT), Allahabad, 1981, 22p.

2. A Building Manual on Windmill Technology. IERT, Allahabad.

ARUSHA WINDMILL

Designer :

Dick Stanley, staff member of Arusha Apppropriate Technology Project.

Institutional Affiliation :

Arusha Appropriate Technology Project,
Box 164, Arusha,
TANZANIA.

Background :

The design was evolved over a period of 18 months of research and testing as part of the work pertaining to installation and maintenance of rural water systems under the Ministry of Water Supply, Arusha, Tanzania.

Application :

The windmill can be used for pumping water from deep wells (76 m 250 ft. and deeper) as well as for low-lift, high-volume irrigation.

Type :

Horizontal axis, multidirectional metal blade windmill. (Fig. 66)

Suitability :

Arid zones prone to multidirectional winds with wind velocities up to 40 kmph.

Design Features :

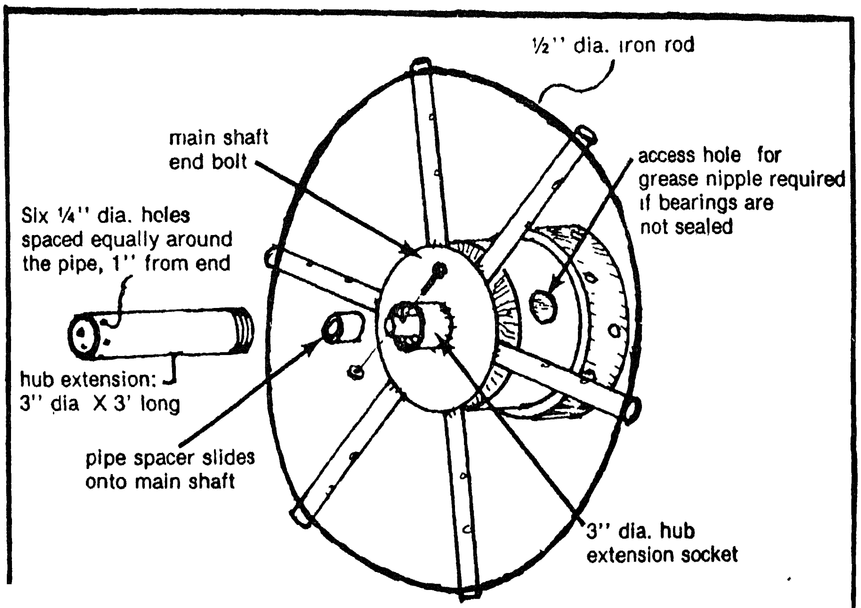
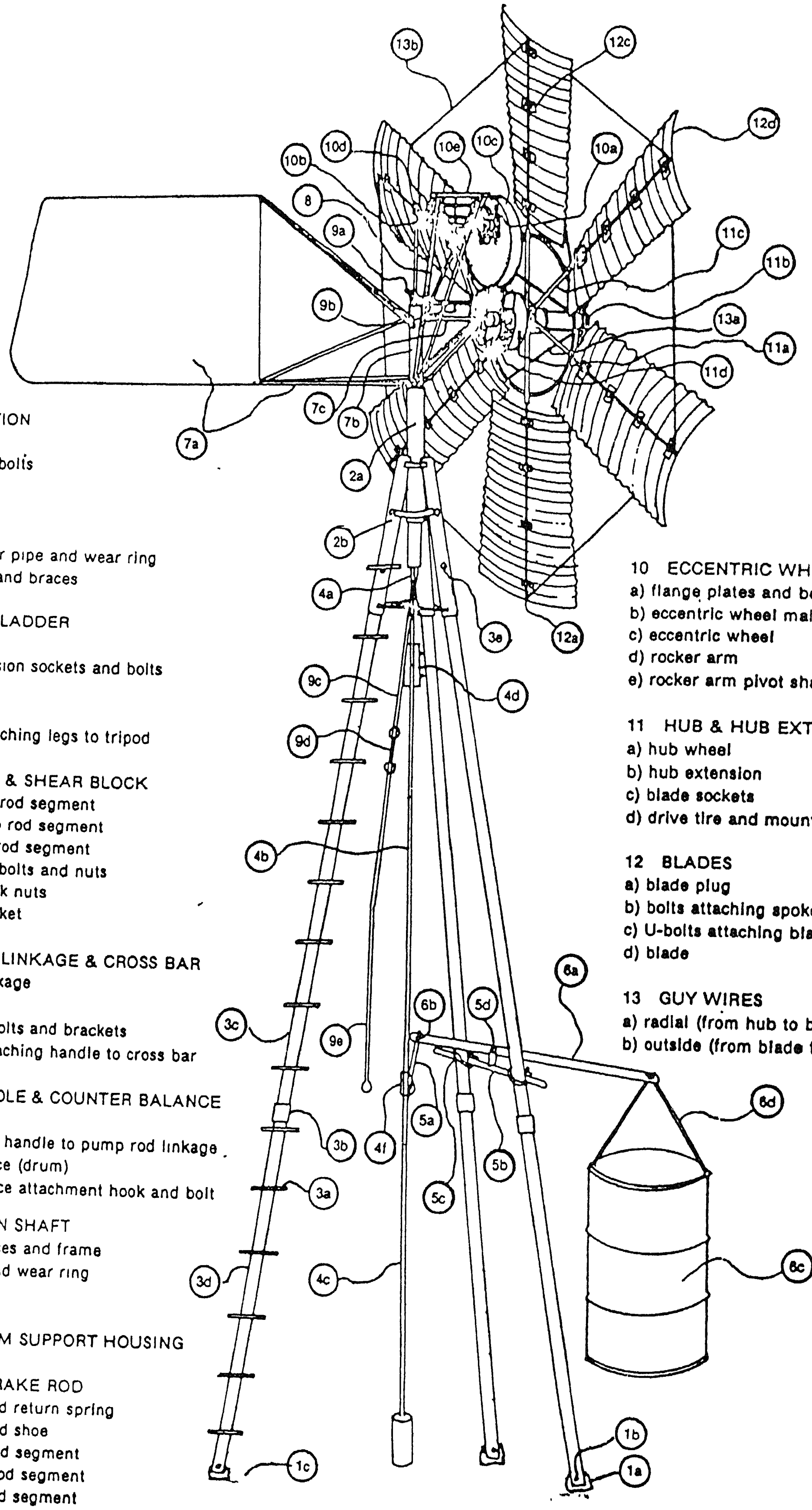


Fig. 65: Hub Wheel of Arusha Windmill



ATION
ns
n bolts
c) concrete

2 TRIPOD
a) tripod center pipe and wear ring
b) tripod legs and braces

3 TOWER & LADDER
a) ladder
b) tower extension sockets and bolts
c) upper legs
d) lower legs
e) bolts for attaching legs to tripod

4 PUMP ROD & SHEAR BLOCK
a) upper pump rod segment
b) middle pump rod segment
c) lower pump rod segment
d) shear block, bolts and nuts
e) pump rod lock nuts
f) pump rod socket

5 PUMP ROD LINKAGE & CROSS BAR
a) pump rod linkage
b) cross bar
c) cross bar U-bolts and brackets
d) pivot bolt attaching handle to cross bar

6 PUMP HANDLE & COUNTER BALANCE
a) handle
b) bolt attaching handle to pump rod linkage
c) counter balance (drum)
d) counter balance attachment hook and bolt

7 TAIL & MAIN SHAFT
a) tail vane, braces and frame
b) center pipe and wear ring
c) main shaft

8 ROCKER ARM SUPPORT HOUSING

9 BRAKE & BRAKE ROD
a) brake lever and return spring
b) brake shaft and shoe
c) upper brake rod segment
d) elastic brake rod segment
e) lower brake rod segment

10 ECCENTRIC WHEEL & ROCKER AR
a) flange plates and bearing housing
b) eccentric wheel main shaft
c) eccentric wheel
d) rocker arm
e) rocker arm pivot shaft and end bolts

11 HUB & HUB EXTENSION
a) hub wheel
b) hub extension
c) blade sockets
d) drive tire and mounting bolts

12 BLADES
a) blade plug
b) bolts attaching spokes to hub wheel
c) U-bolts attaching blades to spokes
d) blade

13 GUY WIRES
a) radial (from hub to blade tip)
b) outside (from blade tip to blade tip)

Fig. 66: The ARUSHA Windmill

The hub wheel is the central rotating part of the windmill. It comprises of a metal wheel rim made from 3.2 mm (1/8") thick plate inside on which are fitted three 30.5 cm (12") dia. steel disks. A 64 mm dia. ($2\frac{1}{2}$") pipe passes through the centre of the discs and houses two ball bearings about which the hub rotates. This assembly slides on the main shaft, (a steel rod 13 mm ($\frac{1}{2}$") dia.; 406 mm (2'4") long, welded to the tail centre pipe) and the hub is held in place on the shaft with a bolt (Fig. 65). Six hub sockets carry spokes for the blade assembly. A 10.2 mm (4") wide strip of rubber type bolted to the back end of the hub wheel provides a friction surface for the brake shoe (for stepping the windmill) as well as for driving the eccentric wheel.

Blades : (See Fig. 67)

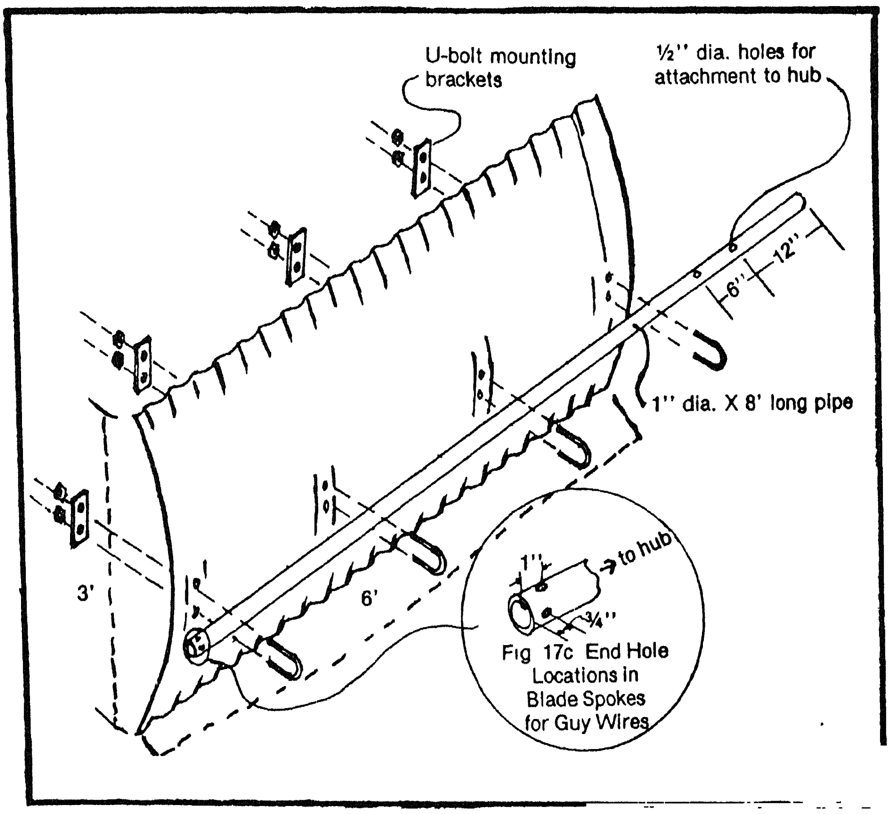
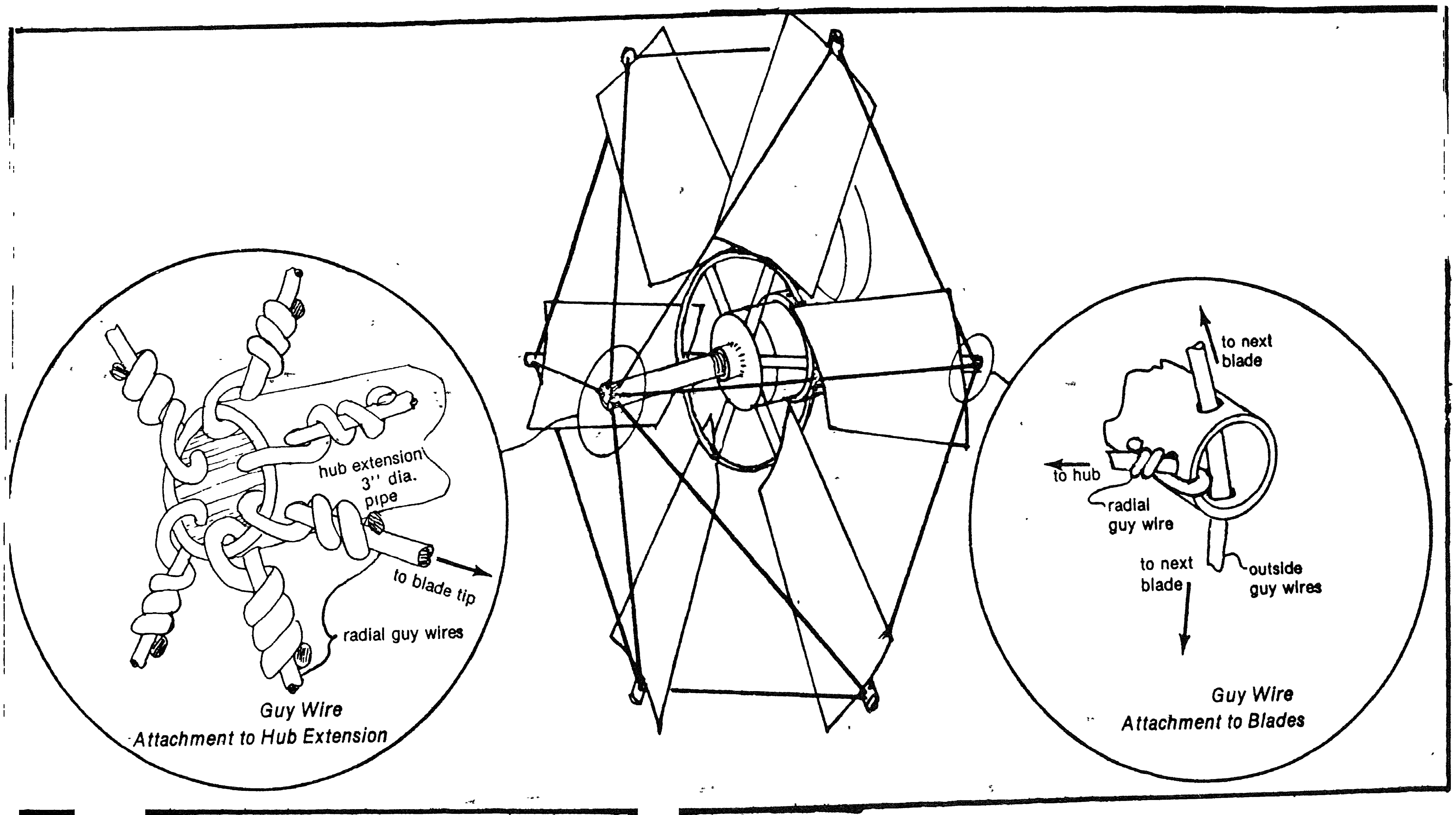


Fig. 67· Blade and Blade Spokes

Six metal blades of 24 or 28-gauge galvanized corrugated sheet metal have been used. Each blade is fastened to a spoke 25.4 mm (1") dia., 203 mm (8") long with U bolts (Fig. 67). These spokes fit into the hub sockets. Two types of guy wires are used to strengthen the blades - one is a set of radial wires going from the tip of the hub extension to the blade tips; the second set connects the tips of the blades (Fig. 68).

Fig. 68· Guy Wires



Tail Assembly :

A relatively flat and sturdy tail frame is fabricated from a 19.5 mm (3/4") dia rod (see Fig. 66) and welded to the tail centre pipe. Sheet metal is now on to the frame. Though the exact tail shape is not important, it should be as flat as possible. The tail helps in orienting the blades to face the oncoming wind.

Power Transmission :

Power is transmitted from the rotating hub on to an eccentric wheel by friction. This produces a reciprocating (up and down) motion on the pump rod through a rocker arm mechanism. This matches optimum pumping speed to optimum blade speed without the use of gears; three turns of the blade assembly are converted to two strokes of the pump. A different ratio could be obtained by using a smaller or a larger wheel. (An axle mounted on the moveable flange on the eccentric allows the pump stroke to be set between 51 mm and 305 mm (2" and 12").

Pump :

The eccentric wheel mechanism operates a reciprocating pump in a deep-bore hole. The windmill pump rod which is a 29' 6" piece of 5/8" steel rod seperated at two points, which extends from the top of the windmill down to the pump at the base of the windmill (see Fig. 66). The bottom pump rod segment extends from the pump handle linkage to the pump itself. The pump can be a conventional piston pump whose pump rod is screwed directly into the bottom of the pump rod socket.

Counterbalance :

An old oil drum with a few holes in the bottom to allow drainage of rain water is attached to a pump handle connected to the pump rod at the other end. Its weight almost equals the weight of the pump rod and piston. Thus, during the upstroke, the windmill has to lift just a little more than the weight of the column of water and this makes the windmill easier to start.

Tower :

The three-legged tower is made out of 64 mm ($2\frac{1}{2}$") diameter pipes. There are two options for tower height. The first is a 6 m (20 foot) tower using only the standard 6 m (20 foot) lengths of metal pipe. The second is a 8 m (26 foot) tower requiring 3 additional 1.6 m (6 foot) lengths of tower pipe.

The tower legs are bolted to steel bars which have been placed into the foundation.

One leg of the tower is made into a ladder by welding metal rods 19 mm x 25 mm (3/4" x 1") along the inside of the tower leg (see Fig. 66).

A tripod connects the legs of the tower and forms the central support housing for the windmill.

Foundation :

A foundation is needed to securely hold the windmill in place. This consists of 3 holes filled with concrete in which anchor pins are placed to connect the foundation with the tower legs. The foundation should be prepared at least 3 days before the windmill is installed.

Braking :

A brake rod extends from ground level up through the centre pipe.

A brake lever connects the brake rod to the brake shaft and is attached to a return spring which pulls the brake away from the hub wheel when the brake rod is released. A housing of 2.54 cm (1") diameter pipe supports the brake shaft and allows it to rotate. A curved steel plate welded to the brake shaft acts as the shoe. When the brake rod is pulled, the shoe rubs against the rubber tyre on the hub wheel and brings the rotor to a halt.

Operating Data :

Rotor diameter : 5 m
Output : 3 hp @ 32.2 kmph windspeed

Static head	Discharge
122 m (400 ft)	1135 lph @ 24.2 kmph
1.8 m	1514 lph @ 8 kmph

Conclusions :

The windmill is made largely out of water pipes of standard sizes and materials commonly available in small rural towns. However, certain basic metal working equipments like welding machines and cutting torches are required for construction.

Several of these windmills were completed by May 1976 and were installed and operated on test sites in the field for a total of over $2\frac{1}{2}$ years equivalent operating time. The whole unit has been tested to withstand a load of 453 kg while in motion with no failure occuring during the testing period of 3 months. Various alterations can be made for meeting local conditions or for lowering the cost of the windmill. These alteratios include using wood for the tower, and a simple crank drive mechanism instead of eccentric wheel design; the blades could be made of wooden poles 5. 1 cm (2" dia.) and heavy cloth etc. (See Referenc e)

Reference :

1. The Arusha Windmill: A Construction Manual by Dick Stanley. Mt. Rainier, Volunteers in Technical Assistance, 1977. 58p.

ITDG WINDMILL

Designers :

Peter Fraenkel, John Dixon, John Armstrong and others.

Institutional Affiliation :

Intermediate Technology Development Group,
9, King Street,
London WC2E 8HN,
U.K.

Background :

Design and construction began in December 1975 at Reading University, U.K., and the prototype was completed by August 1976. The project was initiated to investigate the possibility of developing a windmill suitable for small-scale local manufactures in developing countries. The second phase involved constructing nine further prototypes in different countries to test the manufacture and make necessary modifications and conduct field trials based on the experiences of the U.K. prototype.

Type :

Horizontal axis multi-bladed metal windmill. (See Fig. 69)

Application :

A dual-purpose windmill having one version designed for low-lift high volume crop irrigation and another for high lift low volume

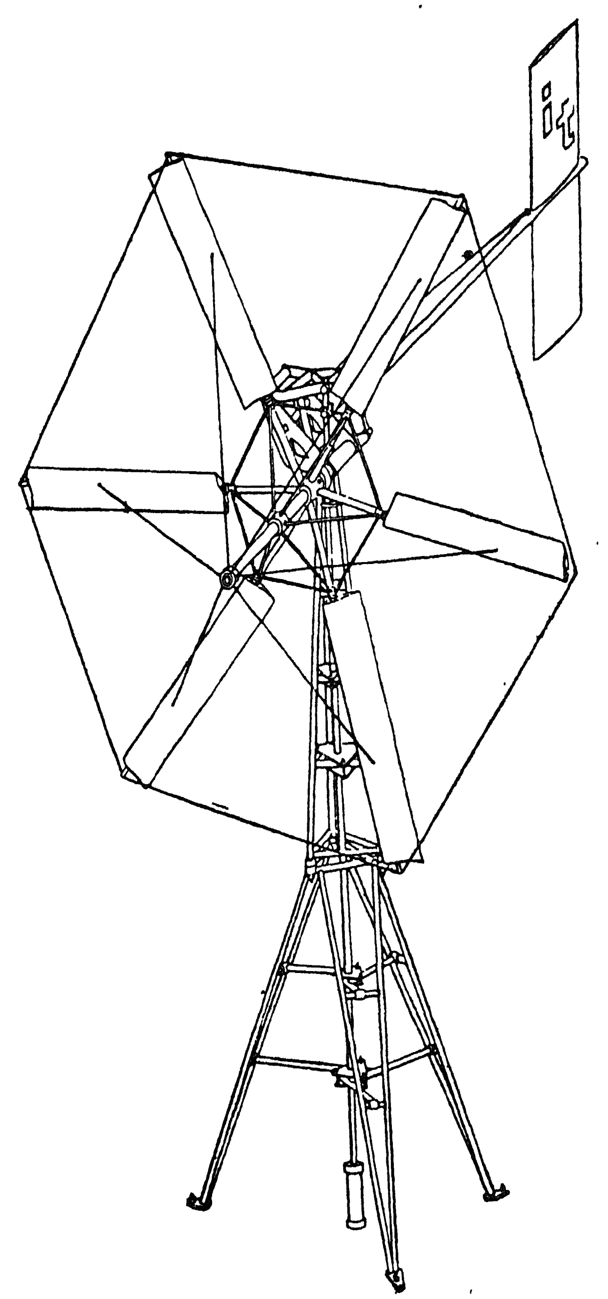


Fig. 69: ITDG Windmill

borehole water pumping.

Suitability :

Arid regions prone to multidirectional winds having windspeeds as low as 5 km/hr with occasional storms up to 50 km/hr.

Design Features :

Rotor Assembly : (See Fig. 70)

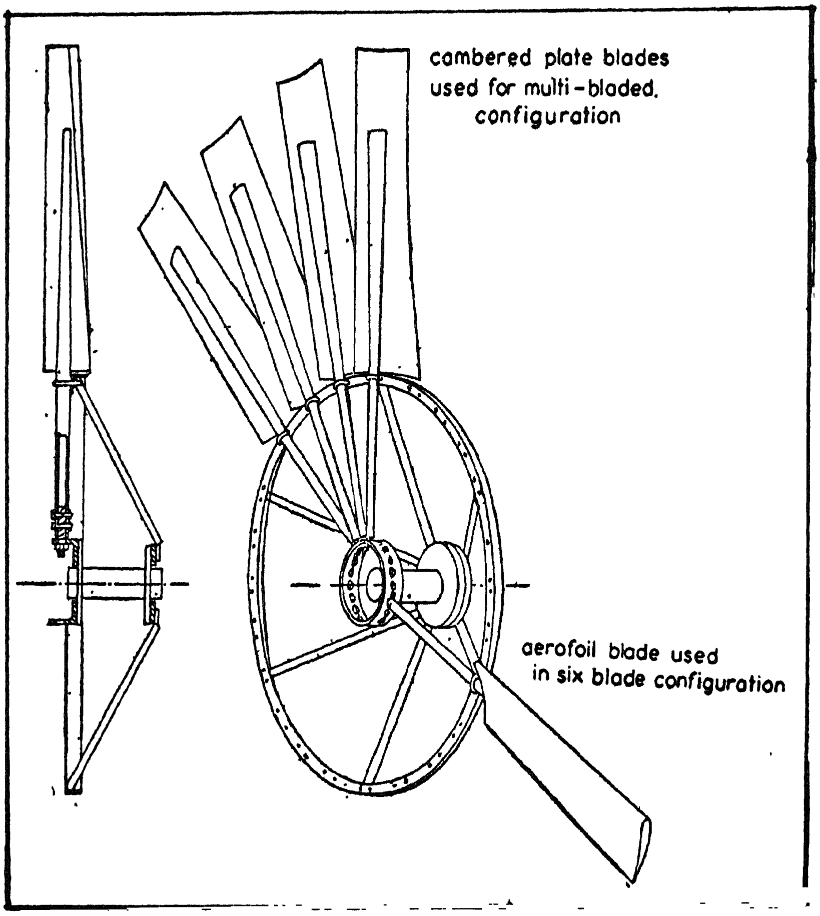


Fig. 70: Multi-purposes Rotor Hub

This comprises of an all-purpose hub (Fig. 73) designed to carry a variable number of cantilevered blades. The high-speed version suited to low lift applications carries six aerofoils, each made by folding aluminium skin-sheets lengthwise to form their leading edge and then wrapping them around a spar located at 1/3 chord and rivetting the trailing edges together by hand. Polyurathene foam mixture is filled to give the blade more rigidity. Blade twist is provided to achieve adequate starting torque. The high solidity rotor design for borehole pumping has

24 aluminium or galvanised steel cambered plate blades each carried on a progressively tapered tubular steel spar.

Transmission :

In the prototype, the main shaft has sealed oversize ball bearings. Rotary motion at the shaft is converted to reciprocating motion by a crank and rocker arm arrangement to drive a double acting piston pump. (Fig. 71)

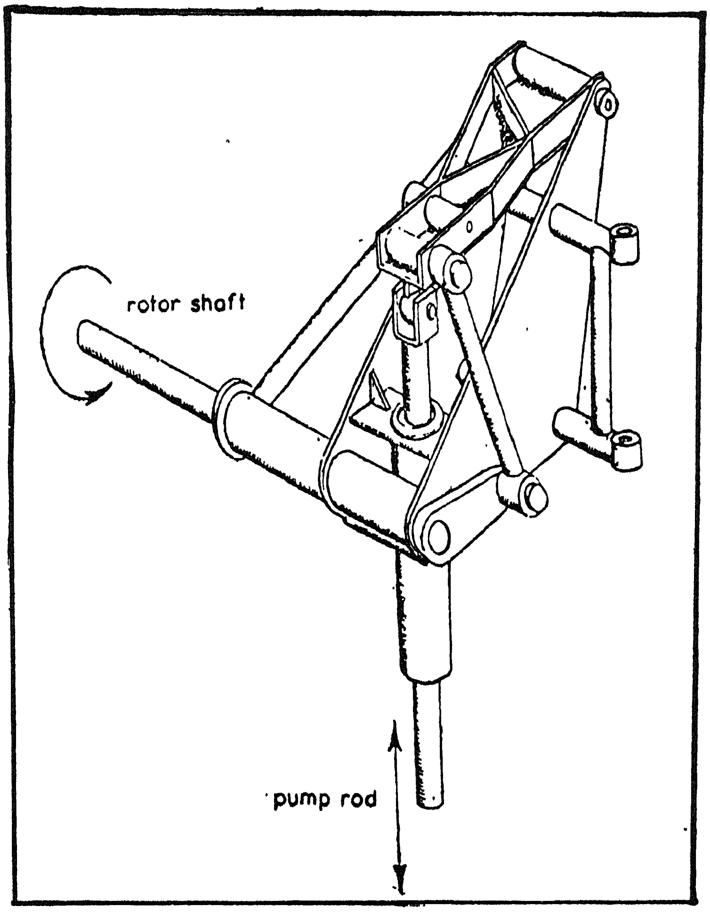


Fig. 71: ITDG Windpump Transmission System.

Rotary bearings marginal lubrication (Glacier DX, an acetal resin copolymer bearing on a bronze substrate) and another self lubricating type (Glacier Du, polytetrafluoro-ethylene on lead compound) have been used. A disc of hard nylon acts as the main transmission support thrust bearing sandwiched between the transmission and the tower top face. The transmission chassis frame, radius arm, mainshaft housing and tower pivot journal are all made up from mild steel plate and tubing.

Pump :

ITDG developed a double-acting piston pump for low-head, high volume pumping which consists of a PVC (Polyvinyl-chloride) cylinder with steel chambers at each end, each fitted with an inlet and outlet valve and a closed aluminium piston fitted with a pair of leather cup seals. The pump has a bore of 150 mm (6") and a maximum stroke of 300 mm (12").

Tail assembly :

The tail fin is a sheet of 22 awg aluminium folded, pop-rivetted to a spar at 1/3 chord and then rivetted at its trailing edge. The assembly is slotted into a tubular tail boom and finally filled with polyurathene foam just like the aerofoil rotor blades, to give it sufficient rigidity.

Storm Protection :

The rotor centre is offset from the tower centre, so that if unrestrained, the rotor would automatically try and rotate itself about the vertical tower axis into a downwind position. The tail boom is pivoted behind the transmission and held into a position perpendicular to the rotor plane by a spring. As soon as wind loading on the rotor exceeds a predetermined level, the spring pretension is overcome and the rotor, together with the transmission, folds towards the tail boom and presents a reduced area to the wind. Adjustment is possible by varying the spring attachment position. In case of spring or attachment breakage, the windmill furls thereby rendering the system fail-safe. A small damper is also fitted to prevent over-rapid furling after a severe gust dies down and also to prevent risk of blade damage due to dyroscopic forces when furling.

Furling :

The U.K. prototype is furled by a detachable pull chain that can be manually clipped to the boom so as to pull the rotor out of the wind against the spring loading from ground level via a single pulley. Other versions under construction have provision for threading a furling chain from the boom via a system of pulleys, through the tower head so that the chain can be left permanently in place and be winched from ground level to deactivate the system as and when required.

Tower Structure :

The U.K. prototype is on a lightweight tubular steel tower 6 m high consisting of a top frame assembly mounted on three ladder-like legs. It was designed to be dismantled into components small enough to be carried in a vehicle such as a jeep. The overseas prototypes incorporate a modular version built up in 3 m high sections. There are six three-legged tower modules in all, the minimum tower height comprising of the top two modules being 6 m and the maximum using all modules being 18 m. The tower is a tripod with tubular legs braced apart by horizontal triangular frames at the base of each module and then tensioned with diagonal cross braces.

An important feature of the tower is that two of the legs are hinged to the foundations in order to permit the entire windmill to be assembled horizontally on the ground and then to be pulled up to the vertical portion with the aid of a winch or by using a vehicle. Nuts on the tower structure are made captive by welding them in place while bolts are high-tensile headed type.

Operating Data :

Rotor diameter : 6 m.
Pump : Double-acting reciprocating pump with pvc pump barrel; aluminium piston fitted with leather cup seals. Pump incorporates controlled leakage to facilitate starting.

Prototype Pump Bore : 150 mm; stroke : 300 mm.
Discharge : 10.6 litres per rotor revolution.

Conclusion :

The windmill is suitable for small-scale manufacture and involves production techniques normally available in medium sized engineering and maintenance workshops. When the overseas prototypes are complete and have had a suitable period of trial, the organisation plans to provide a design package detailing the construction of several variants found to be most satisfactory. This will be made available for use by organisations processing suitable construction facilities in developing countries. The ITDG is in commercial production in India, Kenya and in Pakistan and prototypes now exist in Botswana and Kenya and one is under construction in Egypt.

References :

1. 'International development programme to produce a windpowered water-pumping system suitable for small-scale economic manufacture' by P.L. Fraenkel. Second International Symposium on Wind Energy Systems held at Amsterdam during Oct. 3-6, 1978. Paper H1.

2. 'ITDG international windpump programme; engineering design considerations used in developing a windpump systems for small-scale manufacture and use in underdeveloped arid or semi-arid regions' by P.L. Fraenkel. Proceedings of the Indian Academy of Sciences, Vol. C2, 1; March 1979; 83-105.

AUTO-SPARE INDUSTRY'S WINDMILL

Designer :

Vijay C. Shah.

Institutional Affiliation :

Auto Spare Industries,
Wind Machines Division,
C-7, Industrial Estate,
Pondicherry 605 004,
INDIA.

Background :

After test and trial of two windmill models a final design was brought out. Two models, DW-400G and DW-200G, have been standardized and are now commercially available.

Applications ·

For pumping water from wells or borehole in remote countries.

Type :

Horizontal axis, metal blade windmill. (Fig. 72)

Design Features :

Rotor Assembly :

The rotor consists of :

- 12 blades made of GI sheets which are bent and fixed to give the necessary twist.
- a hub, in the form of a welded cage, which provides rigidity to the rotor by means of 6 tension spokes. The hub is mounted on the main shaft and can be bolted and locked.

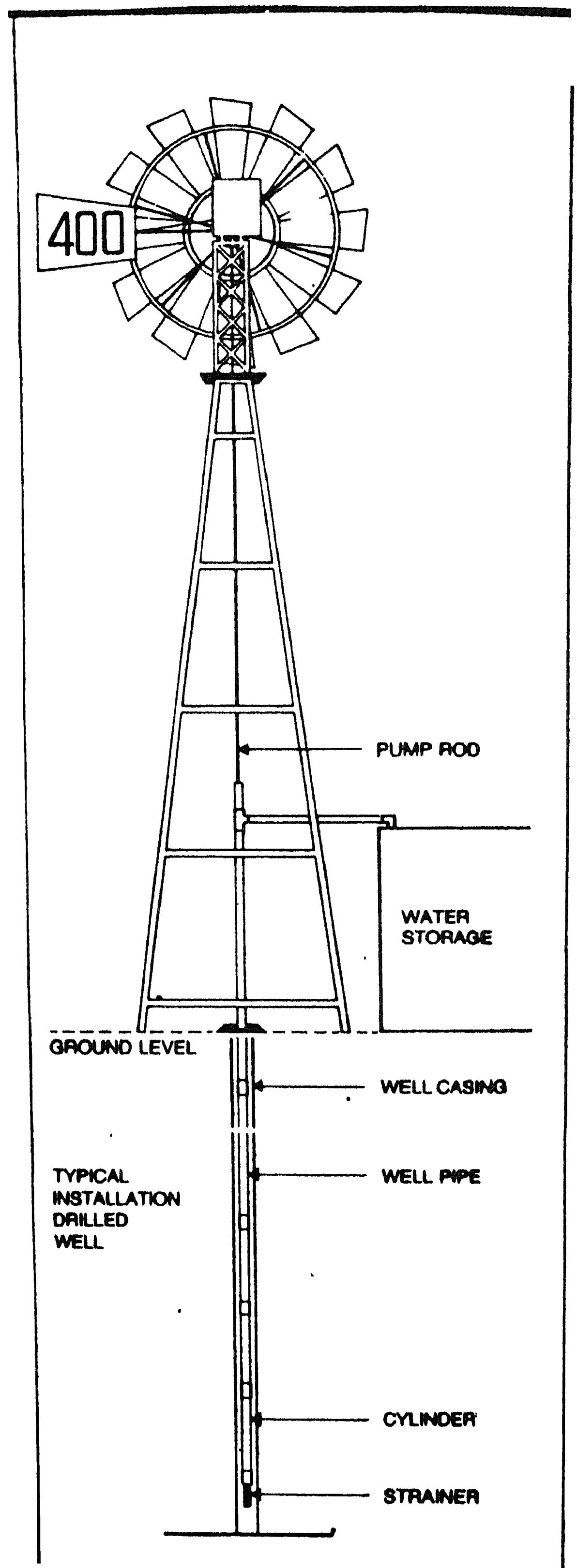


Fig. 72· (Model DW-400G)

Turntable :

The turntable consists of two rows of ball bearings and helps to keep rotor wheel always facing the wind.

Transmission :

Two pinion gears pinned to the main shaft drive the two seats of back gears provided on either side of the pump rod, to distribute the load evenly and assure less wear and long life of the mechanism. The pitman is connected from the offset hub of the large gears to the rocker arm, the back end of which is connected to a fixed support. The pump rod is connected to the moving end of the rocker arm and as the wheel turns the main shaft, the train of the mechanism produces the up-and-down stroke of the pump rod.

Oiling Mechanism :

The oiling system circulates oil freely to all moving parts and the main gears run in oil assuring minimum wear and longer life. The oil needs to be changed once a year.

Tail Vane

The vane serves as a rudder to keep the wheel in the wind under variable conditions. It can also be used to turn the rotor out of the wind when not in operation. Further, automatic regulation is achieved by balancing the wind force on the vane and rotor by means of a weight.

Tower :

Two types of towers have been tried. A steel stub tower mounted on top of a Casurina or Eucalyptus pole tower was designed. These towers were provided with proper anchoring and were found to be reliable and sturdy. However, due to the limited life of such a tower (3-4 yrs.) and the fast deterioration of wood by the weather and by attacks of termite a second type of tower was designed. A four-post steel tower made from angle rion was standardised for model DW-400G. The tower is 14 m in height.

Pump :

The pump design consists of a brass cylinder with a brass plunger having a neoprene ball assures a good seating and optimum water output.

The pump rods are made of teakwood poles (4 cm x 4 cm) in lengths of 2. 5 to 3. 5 m joined together by metal fastener.

Operating Data :

Cut-in-velocity - 7/8 kmph
Tip speed ratio - 1. 5 to 2. 5

In rated windspeed of 25 kmph the performance is as under :

	Model DW - 200 G		Model DW - 400 G	
Elevation (m)	Cylinder size (mm)	Rated Pumping Capacity (l/h)	Cylinder Size (mm)	Rated Pumping Capacity (l/h)
5	100	3000	175	18000
30	45	650	80	3300

Conclusion :

The final design has been tested and the first prototype has been working satisfactorily for almost 4 yrs. Two models, DW-400G having 4 m rotor diameter and DW-200G having 2 m rotor diameter have been standardized and are commercially available.

References :

1. "Water pumping windmills for small communities" by Vijay C. Shah. National Solar Energy Convention, Dec. 19-21, 1981 organized by Annamalai University, India. Allied Publishers, New Delhi, 1980, p. 31-35.

2. Brochure - Water pumping windmills published by Wind Machines, Pondicherry.

WP-2 WINDMILL

Institutional Affiliation :

National Aeronautical Laboratory,
Wind Power Division,
Post Bag No. 1779,
Bangalore 560 017,
INDIA.

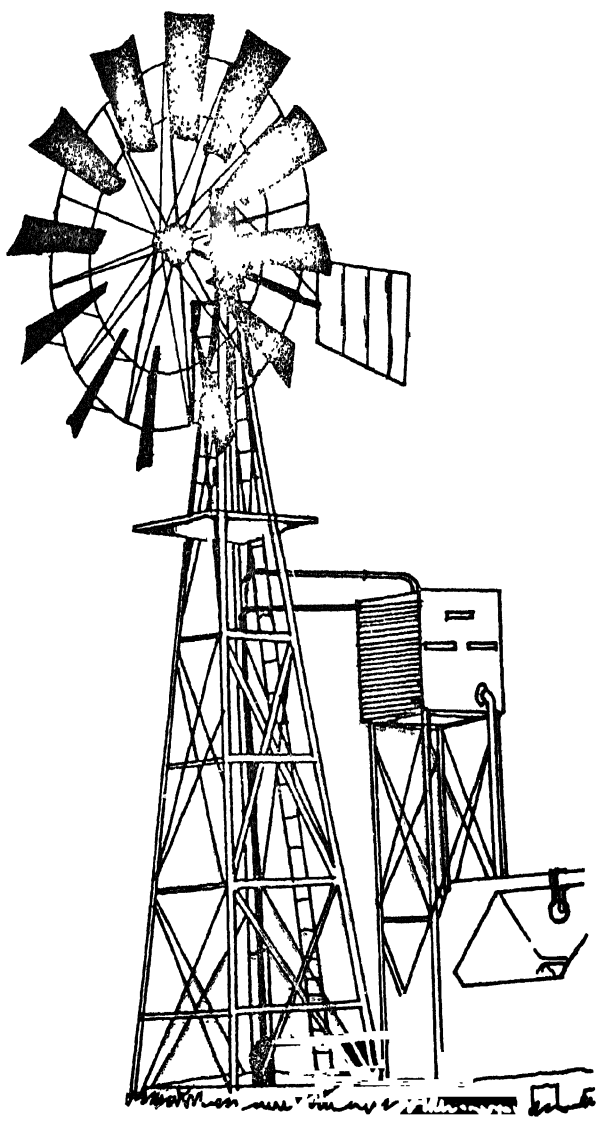


Fig. 73: WP-2 Windmill

Background :

Two types of standard windmills, WP1 type for pumping water for highly windy sites and WP2 type for moderately windy sites were developed at National Aeronautical Laboratory, Bangalore. During the period 1959-64, the windmill WP-2 indigeneously developed at NAL was produced in batches and 80 of these were erected for field trial at several places in India.

Application :

For lifting water for domestic and minor irrigation purposes.

Type :

The WP-2 windmill is a horizontal axis, multibladed direct acting type windmill. (Fig. 73)

Suitability :

Designed for operation in windy regions of the order of 6 to 9 kmph.

Design Features :

Rotor Assembly :

The rotor is 16 ft in diameter. The rotor spiders are fabricated out of galvanised pipe. These are strengthened with tie rods which are kept in tension by means of adjustable eye-bolts. Fittings are provided over the pipes and angles to fix the rings and blades. Two rings are fabricated each of diameter 9 ft and 13 ft and these form the support for the blades (Fig. 74).

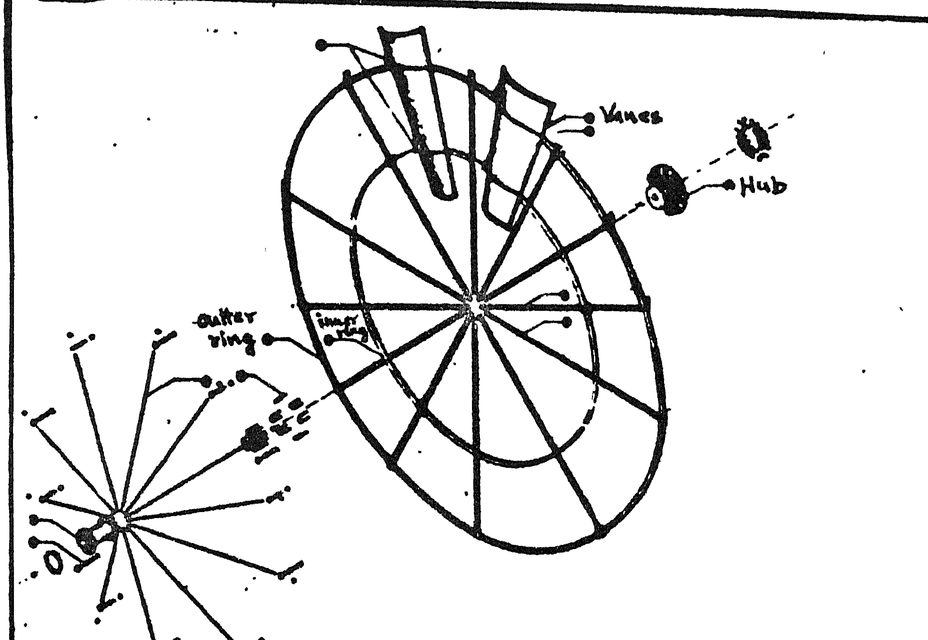


Fig. 74: Rotor Assembly

The rotor pipes and angles are rigidly fixed to a cast iron hub. A pipe fabricated from sheet tube with which two mild steel flanges is provided as an extension to the hub to which the tie rods are fixed.

The hole in the hub for the shaft is 17/8" in diameter. A keyway is also provided to fix the hub to the shaft.

Blades :

There are 12 blades made of galvanised plain sheets. To stiffen the blades and to maintain the shape, a framework is made out of flat sections and fabricated angles. G1 sheets cut to required shape is fixed to this frame by revetting. The inner and outer leading edges of the vanes are set at 45^{o} and 35^{o} respectively to the plane of the rotor such that the rpm does not go beyond 40 at greater windspeed. The inclination is maintained by the vane fittings.

The blades are fixed to the rotor ring with vane fittings that are fabricated out of angle sections. Each blade can be easily fixed or removed independently.

Turntable :

The turntable carries the crank case housing and the head mechanism (Fig.75) and turns over the tower cap to orient itself towards the wind.

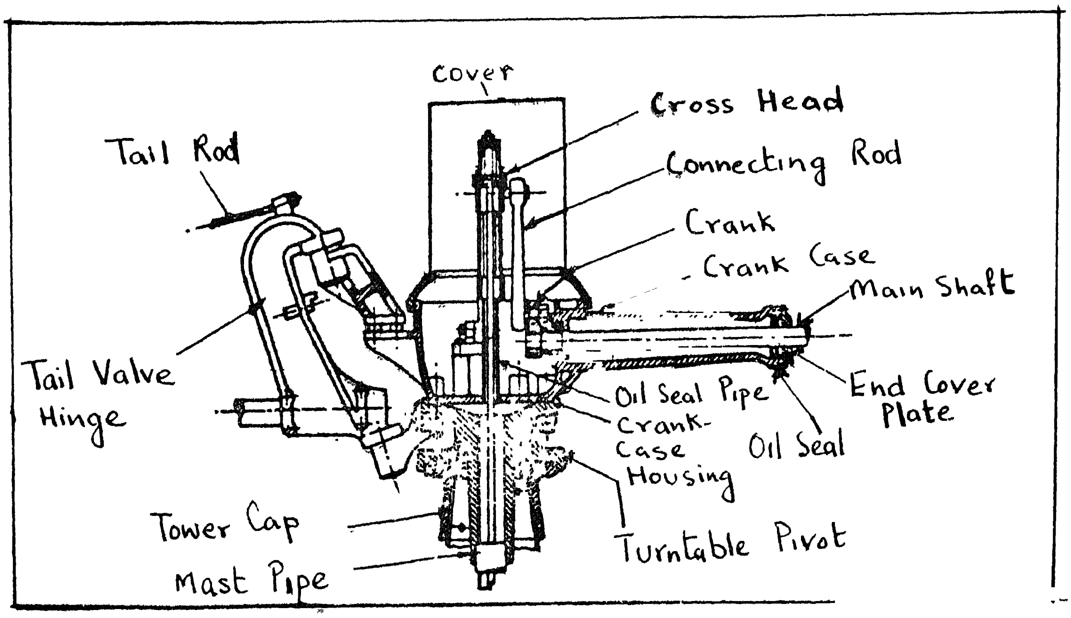


Fig.75: Head Mechanism Assembly

Provision is made in the turntable to lubricate the steel balls over which it turns by providing a grease cup. To prevent the head mechanism from being lifted due to strong squalls from its seat in the row of balls and toppling it down, two brackets are fixed, one on each side of the turntable.

Power Transmission :

The head mechanism contains the arrangement for the conversion of rotary motion obtained from the rotor into reciprocating motion by the slider crank mechanism.

The motor is mounted over a shaft which is offset by $2\frac{1}{2}''$ from the vertical axis of the head mechanism for the purpose of automatic furling. The other end of the shaft carries a crank, connecting rod and cross head combination. Two vertical guides fixed to the crank case are provided for the reciprocating motion of the cross head and this motion is transmitted to the pump by means of vertical pump rods.

Pump :

The pumps used for windmills are of single-acting plunger type pump with a brass cylinder. There are two sizes of pumps of similar design with cylinders of 6" and 4" diameter. The small pump is for use where the depth of the well is more or where there is a possibility of the well getting drained by the continuous working of the windmill. The pump comprises of cylinder, plunger, suction valve, top and bottom plate. (Fig.76)

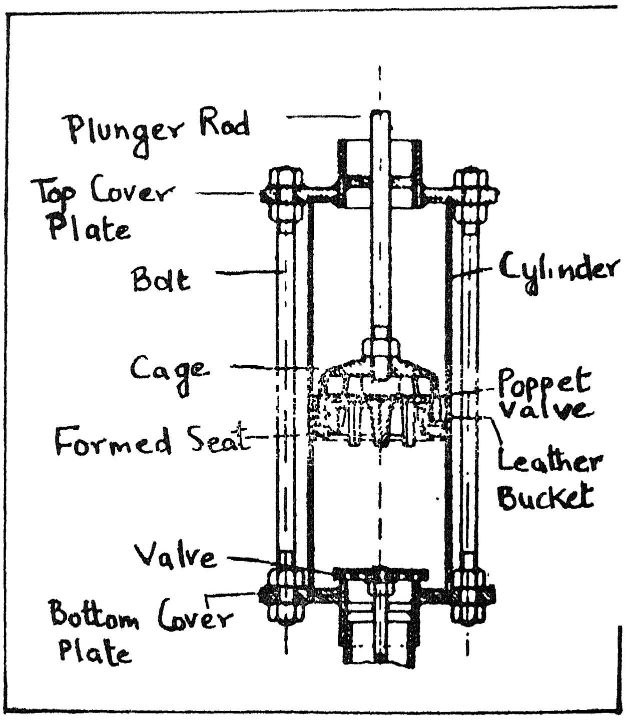


Fig.76: Pump Assembly

Tower :

The tower of a 4-post construction is completely fabricated out of steel. It stands 32 ft above ground and is built in three sections which can be erected section by section.

The corner angles do not overlap but are butted and strapped with an angle-back piece bolted to each section. This ensures greater strength and less of strain on the joint bolts.

The tower legs are made from heavy angle steel. The angle steel grits are placed in the towers every 4 feet 6" apart. The cross braces are of steel angles and provide angle strength to the tower to withstand greater loads. A ladder made in sections with angle sides and steps is fitted to one side of the tower. A rigid hardwood platform is securely fastened to the tower at a convenient height by means of steel angle supports. This ensures accessibility while working on it.

Tail Assembly :

The tail vane is fabricated from galvanized plain sheet of 22 G. This vane is stiffened with flats on one side and fabricated angles on the other side and revetted together. Tail vane is attached to a pipe of 2" bore by means of U bolts. (Fig. 77)

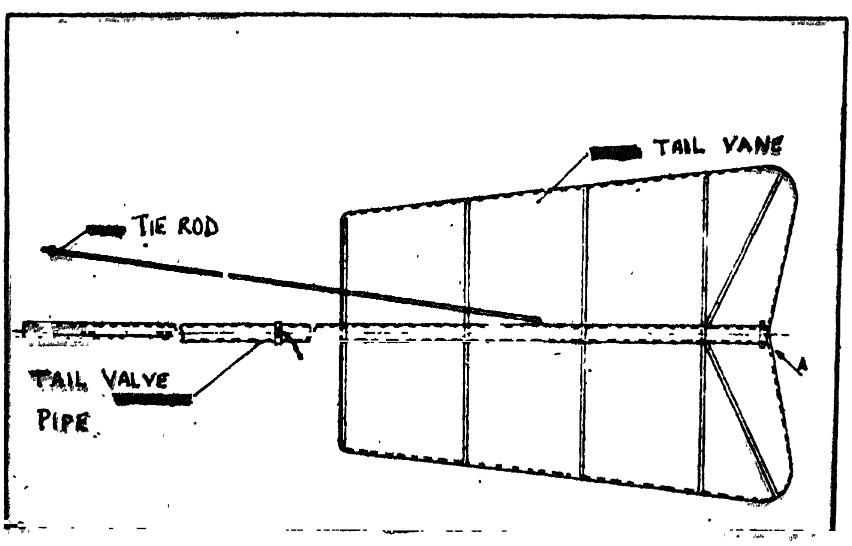


Fig. 77· Tail Vane Assembly

The tail vane makes the rotor face the wind for normal working to turn the rotor away from the wind when furled. It is mounted over the head mechanism and it can turn about the tail vane hinge whose axis is inclined at an angle of 17 to the vertical. This turning motion is to augment automatic furling at higher windspeeds and also to keep the windmill furled during maintenance or in strong wind during storms.

Governing :

Governing is done by the gravity system and is automatic in its action. The axis of the shaft is offset from the centre line of the mast pipe, so that the rotor does not present its full area when the wind exceeds about 40 kmph.

Furling Arrangement :

Arrangement is also made to keep the windmill furled manually during maintenance or when strong winds are expected due to storms. A chain fixed to the tail pipe passes down through the crank case housing and is fixed to a lever kept at a convenient height over the tower. By pulling the lever, the tail is brought parallel to the rotor, thus keeping the rotor in the direction of wind. In this position the rotor cannot rotate.

Operating Data :

Pumping capacities of WP-2 direct acting windmill based on windspeed of 10 mph and 5 inch stroke.

Total lift in feet	280	125	45	30	15
Choice of pump diameter in inches	2	3	5	6	8
Water pumped in gallons per hour	100	230	640	920	1650

Conclusion :

The windmill is basically made of steel and uses a slightly complicated mechanism. Also, the cost of fabrication is considerable, which may be beyond the reach of the individual farmers.

The licence for manufacture can be obtained from the National Research Development Corporation of India, 61, Ring Road, New Delhi 110 024, India.

References :

1. "Direct acting windmill to pump more water now and ever" by NAL, Bangalore.

2. "Instructions for installation and maintenance of WP-2 Windmill". NAL, Bangalore, 1963. 43p.

3. "Specification for WP-2 Direct-acting windmill" by National Aeronautical Laboratory, Bangalore. April 1963, 19p.

BHEL WINDMILL

Contact :

Dr. R.P. Gupta.

Institutional Affiliation :

Corporate Research & Development Division,
Bharat Heavy Electricals Ltd.,
Vikas Nagar,
Hyderabad 500 593,
INDIA.

Background :

Activity in BHEL on the development of a horizontal axis windmill started in 1978.

Application :

Pumping of water for drinking and small irrigational needs of village community.

Type :

12 bladed all metal horizontal axis windmill. (Fig. 78)

Suitability :

Suitable for areas with multi dimensional low wind speeds of 6 to 16 km/hr.

Design Features :

Rotor Assembly :

The 5 meter diameter rotor has twelve number of aerodynamically designed and made of mild steel sheet blades. These blades are fixed to two rings which in turn are fixed to six tubular spars radiating from the rotor hub.. The power shaft to which the rotor is attached is supported on the turn table through two bearings.

Turn table :

The turntable consisting of a box structure is supported on the tower through a thrust bearing. Tail plane and side plane are also fixed to the turntable. The side plane and the tail plane are inter connected such that in heavy wind they automatically get disconnected and then the turntable

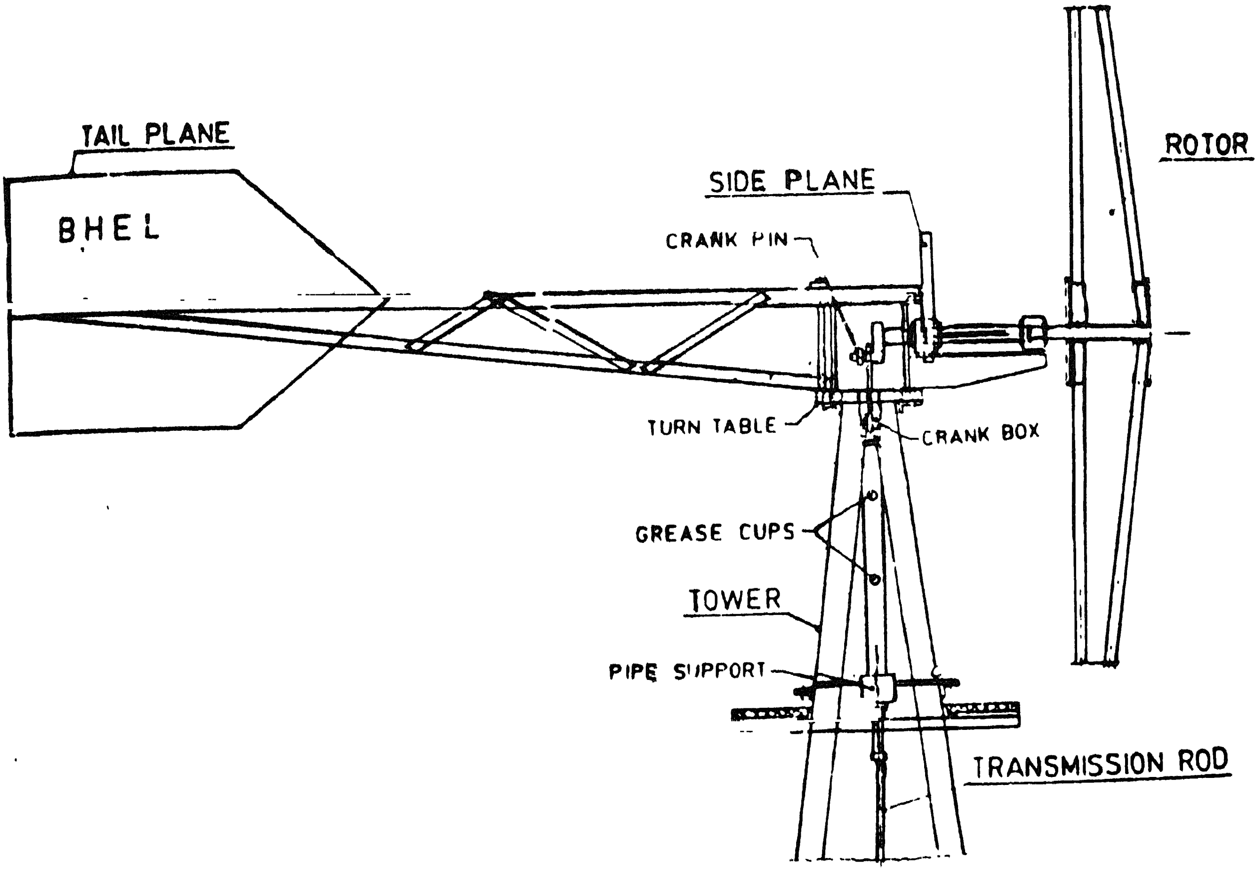


Fig. 78: BHEL Windmill

rotates bringing the wheel parallel to wind direction thus protacting it from strong winds, Turn table also has a pipe welded to it at the lower end which goes inside the tower and is guided at the lower end from supports fixed to tower.

Power Transmission :

The shaft power is transmitted to a reciprocating pump through transmission system involving crank, crank level, transmission rod etc. The reciprocating transmission rod, guided by two bushes fixed inside the turn table support pipe is connected at the upper end to the crank through a crank lever. The lower end is connected to a commercially available pump mounted inside a 150 mm diameter bore well.

During testing it was observed that the pump is under capacity for the windmill. A larger size, double acting, reciprocating pump is under development.

Tower :

The tower is a 7 meter high four legged structure with mild-steel angles and fixed on a reinforced concrete base through foundation bolts.

Technical Data :

Diameter	5 m
No. of blades	12
Solidity	0.40
Tip-speed ratio	2.0
Tower height	7 m
Cut-in wind speed	6 kmph
Design wind speed	12 kmph
Cut-out wind speed	35 kmph
Pump	Single acting, reciprocating dia 100 mm, stroke 150 mm

Performance :

Discharge	2500 liters/hr at 12 kmph windspeed
Head	6 m

Conclusion :

The windmill has been designed and tested as a prototype. It is an all metal construction utilising common mild steel sections available in the market and can be fabricated in a small workshop having normal machines as lathe, drilling, power saw and welding. Based on the experience gained, a modified bigger windmill and larger capacity pump are under development.

Reference :

1. Windmills and wind energy by R. P. Gupta. Rep. No. NCES/17/1980-81, Corp. R&D Div., BHEL, Dec. 1980.

VERTICAL AXIS WINDMILLS

BRI WINDMILL

Institutional Affiliation :

Brace Research Institute,
P.O. Box 400,
St. Anne de Bellevue,
Quebec,
CANADA.

Background :

Brace Research Institute carried out a test-programme on the Savonius rotor to find out its potentialities for low cost water-pumping. The Savonius rotor design used in all these tests is shown in Fig. 79.

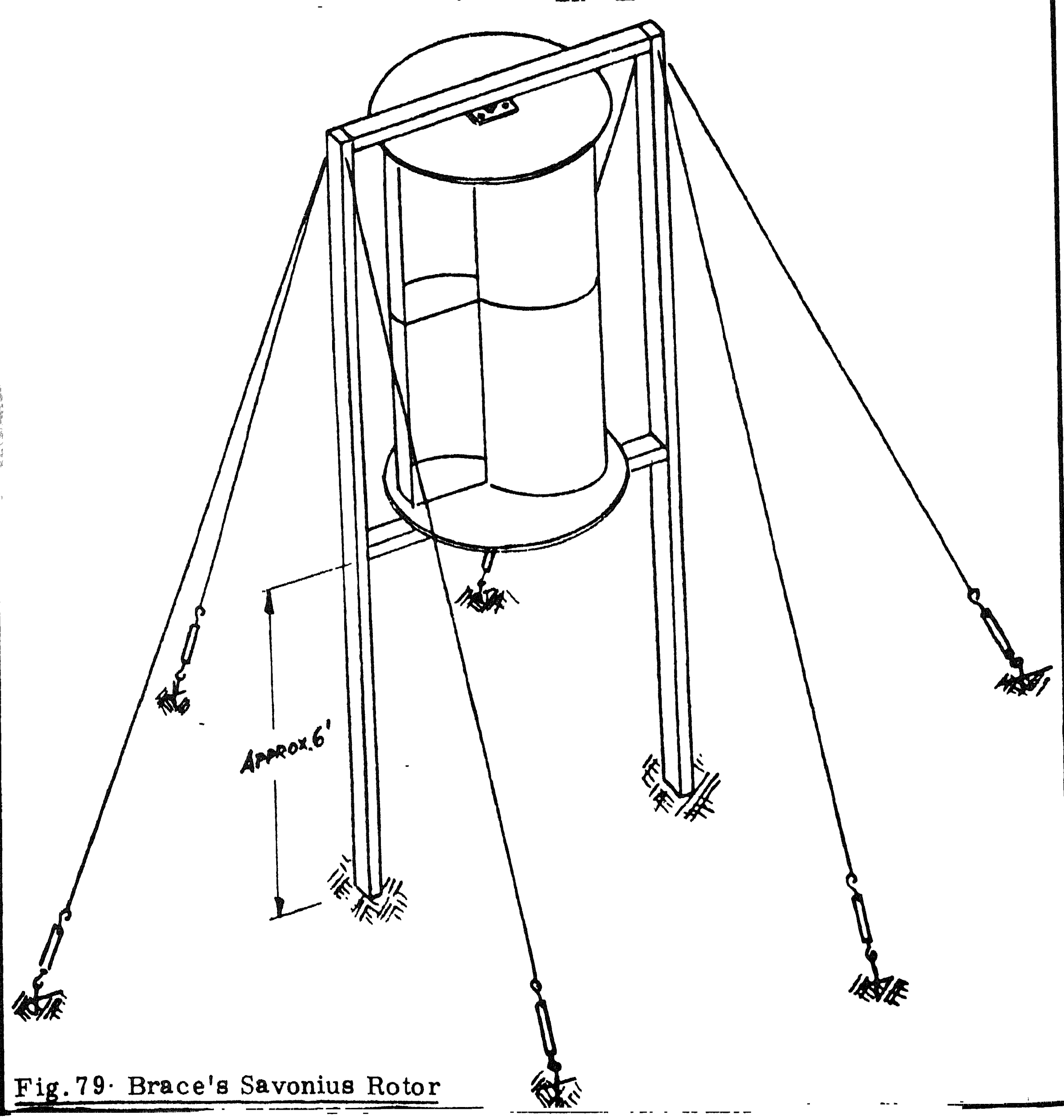


Fig. 79· Brace's Savonius Rotor

Applications :

Pumping water in areas where the water level is not more than 3 - 4.5 m (10-15 feet) below the ground.

Suitability :

In areas with windspeeds of 13-20 km/hr.

Design Features :

Rotor Assembly :

It consists of two 45-gallon oil drums bisected lengthwise and welded together to form two troughs which are mounted between two end plates, made from 12.7 mm ($\frac{1}{2}$") plywood, 1219 mm (48") diameter as shown in Fig. 80.

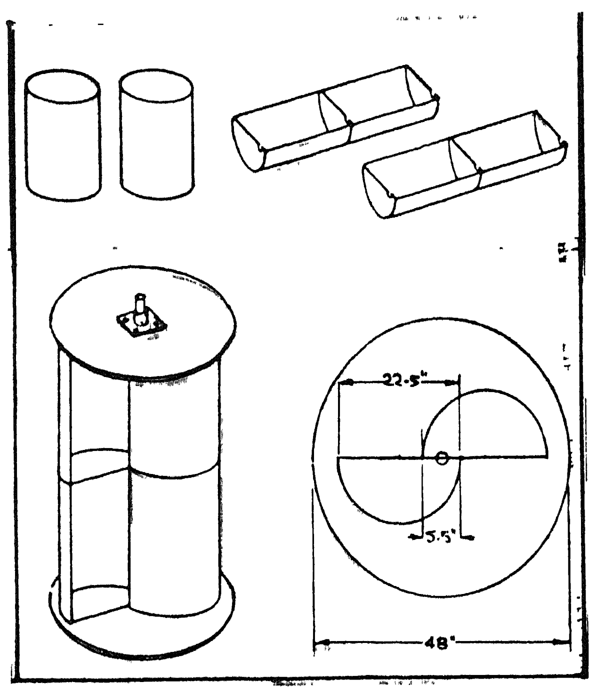


Fig. 80: Rotor Assembly

The ends of the oil drums are bolted to the wooden disk with 9.5 mm (3/8") stove bolts, washers and nuts. A shaft made of 31.8 mm (11/4") ID water pipe passes through the center of the rotor extending about 6" beyond either ends of the end plate. Two flanged collars secure the shaft to the end-plates. Two self-aligning ball-bearings are used to support the rotor shaft in the frame. Two adapters, further fit the two ends of the shaft to the bearing as shown in Figs. 81 & 82.

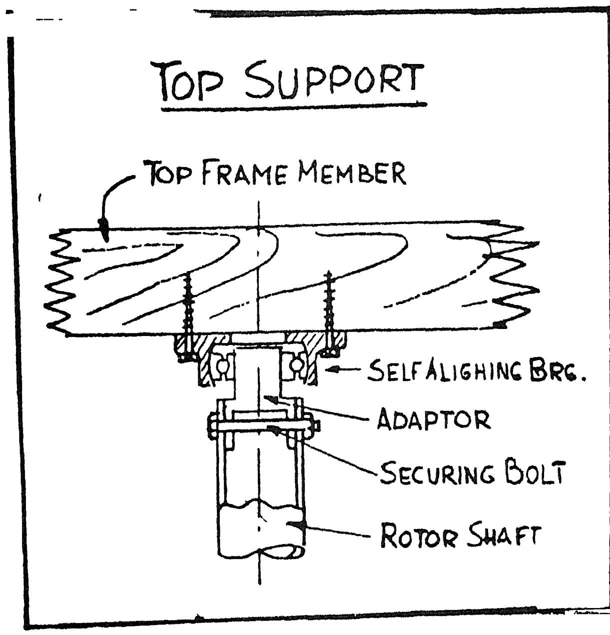


Fig. 81: Top Support of the Rotor

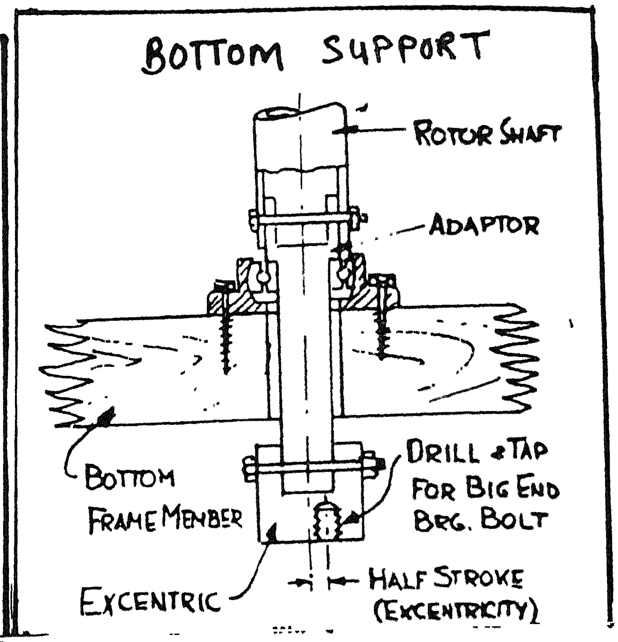


Fig. 82: Bottom Support of the Rotor

The lower adapter after passing through the lower frame carries the eccentric at its lower end. (Fig. 82)

Power Transmission :

As shown in Fig. 83 the drive consists of the eccentric, the connecting rod, the bell crank and the pump rod. The connecting rod which is connected to the eccentric at one end moves forward and backward, which in turn activates the bell crank attached to its other end. The pump rod fixed to the free end of the bell crank thus moves up and down.

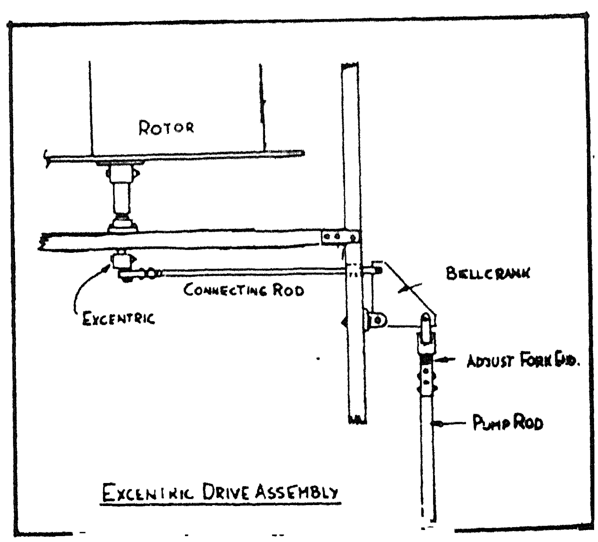


Fig. 83· Excentric Drive Assembly

Pump :

The pump is of the single acting diaphragm type. The diaphragm, which is operated through a stirrup attached to the pump rod, is made from

a piece of inner tube. A flange ring provides the clamping of the rubber diaphragm as shown in Fig. 84.

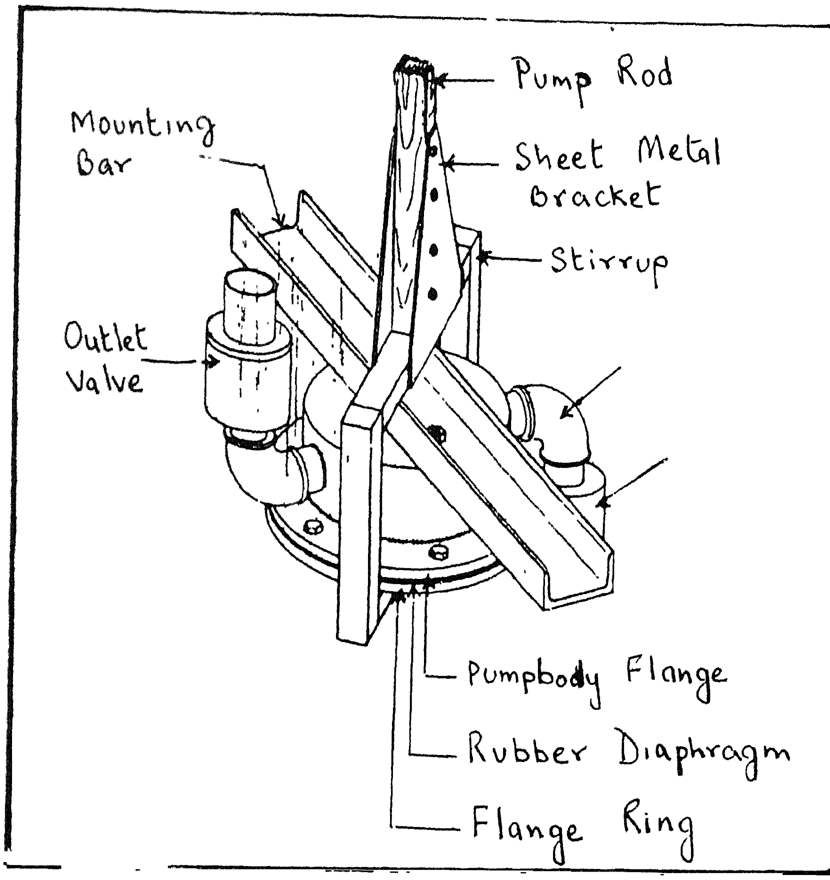


Fig. 84. Single-acting Diaphragm Pump

The flange has 8 bolts around the circumference to ensure good seal. Two 25 mm (1") water pipe nipples are welded on each side for the inlet and outlet valves. The two discs supporting the rubber diaphragm are made from "Tufnol". Clearance between disc and pump rod is kept 0-055 D and sealing compound is applied to the rubber between the discs and the flanges to assure a good seal.

The pump is mounted just below water level (fully submerged).

Tower :

The support frame consists of four pieces of 101.6 x 50.8 mm (4" x 2") timber as shown in Fig. 79. The joints are bolted with gusset plates. The frame is steadied with guy wires, securely anchored to the ground and tensioned by turnbuckel.

Operating Data :

Discharge head - 3.0 m
Diaphragm pump stroke volume - 0.3 dm^3
Discharge - 1080 litres/hr @ 6.2 km/hr.

Conclusions :

Various versions of this unit have been built in developing countries. The construction of the windmill assumes a certain amount of technical knowledge. Manufacturing and assembly can be carried out with local materials and tools. The difficulty may be only in obtaining the ball bearings or carrying out the welding work at the village level.

Reference :

1. How to construct a cheap wind machine fro pumping water. Brace Research Institute, 1975 (revised 1973), leaflet 13 pages.

IRRI SAVONIUS WINDMILL

Contact :

Mr. G.C. Salazar.

Institutional Affiliation :

International Rice Research Institute,
P.O. Box 938,
Manila,
PHILIPPINES.

Background :

The unit was developed as an alternative to the gasoline/diesel engine driven centrifugal pumps commonly used in the Philippines to irrigate rain-fed farms.

Application :

Pumping water from shallow well or canal for irrigation.

Type :

Vertical axis, metal drum, Savonius rotor. (Fig. 85)

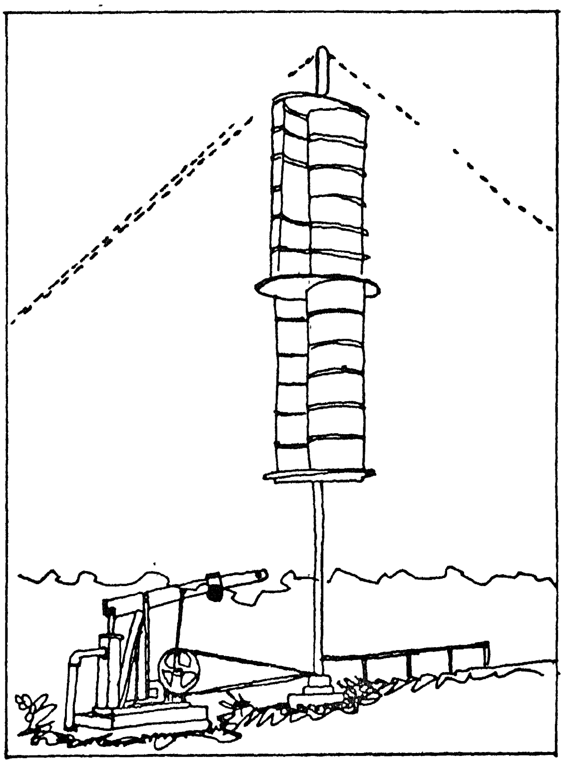


Fig. 85: IRRI's Metal Drum Savonius Rotor

Suitability :

Areas prone to multidirectional winds in the range of 15-30 kmph.

Design Features :

Rotor Assembly :

The rotor is fabricated from four 200 litres (45 gallons) oil drums cut in half lengthwise. The shape of the drum is modified slightly to obtain more aerodynamic efficiency. The drum halves are welded to a 6 m section of a 100 mm (4") schedule G.I. pipe. The pipe is mounted vertically with bearing supports at the top and bottom. The pipe serves both as a tower and a rotating shaft. Three 8 mm diameter guy wires are attached to the top bearing to stabilize the rotating structure. (Fig. 85)

Power Transmission :

A transmission belt transfers the power from a pulley located near the edge of the rotating shaft (vertical pipe) to another pulley with a crank and lever mechanism operating a piston pump. (Fig. 86)

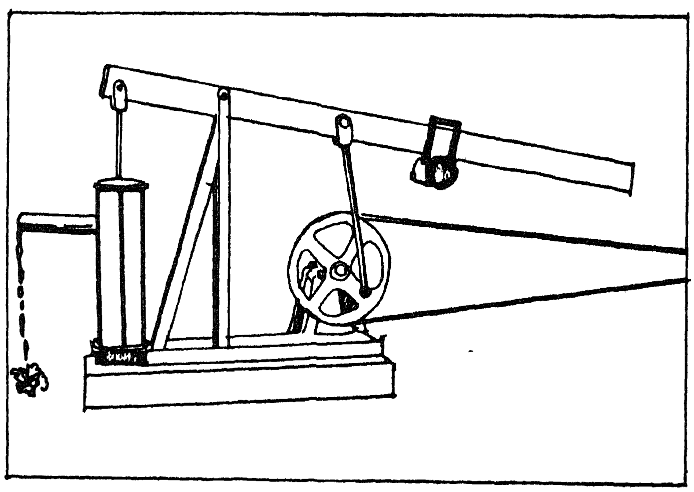


Fig. 86: Piston Pump and Pulley with Transmission

Pump :

The windmill drives a simple 15 cm diameter piston pump employing a PVC cylinder. A locally available leather cup serves as water-seal between the cylinder wall and the piston assembly. There is also a provision for manually operating the pump in case of prolonged windless period.

Operating Data :

Pump : Piston pump with PVC cylinder, 15 cm dia.
Discharge : (litres/hr)

Wind Speed			Suction lift (m)	
km/h	1.5 m	3.0 m	4.6 m	6.1 m
14.5	4,010 l/h	2,005 l/h	1,340 l/h	1,000 l/h
16.1	5,530 l/h	2,760 l/h	1,820 l/h	1,380 l/h
19.3	9,535 l/h	4,770 l/h	3,180 l/h	2,385 l/h
24.1	18,700 l/h	9,350 l/h	6,210 l/h	6,655 l/h
32.2	44,290 l/h	22,145 l/h	14,760 l/h	11,053 l/h

Conclusion :

The windmill design is simple and rugged and makes use of locally available materials and manufacturing capabilities. The performance of the windmill has been taken up for evaluation by IRRI Cropping Systems and rice production departments with eight demonstration units at selected locations in the Philippines having varying wind conditions.

Reference :

1. 'IRRI-Designed Windmill/Piston Pump', by G.C. Salazar. Economic and Social Commission for Asia and the Pacific, Workshop on Biogas and other Rural Energy Resources (Energy Resources Development Series No. 19). New York, U.N., 1979. p. 90-103.

SUNFLOWER SAVONIUS WINDMILL.

Institutional Affiliation :

Sunflower Power Co., Inc.,
Route 1, Box 93-A,
Oskaloosa, Kansas 66066,
U.S.A.

Background :

A plan to build a Savonius rotor wind turbine for water pumping by the Sunflower Co. is described below.

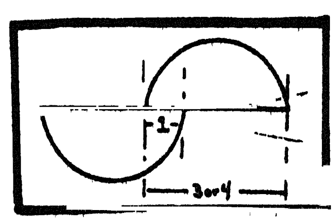
Type :

Vertical axis, metal drum, Savonius rotor (Fig. 87).

Design Features :

Rotor Assembly :

The rotor is made of two 55-gallon oil drums cut in half lengthwise and welded or bolted end-to end. The barrel must be overlapped in the ratio 1:3-1:4.



The central shaft made of 38 mm ($1\frac{1}{2}$") I.D. galvanized water pipe passes through the centre of the rotor and is threaded on each end. The end discs of the rotor should be 1.25 times the diameter of the barrels and can be made out of sheet metal or plywood.

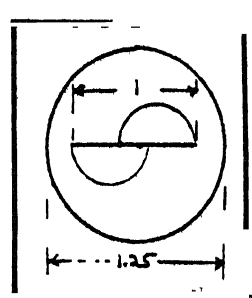
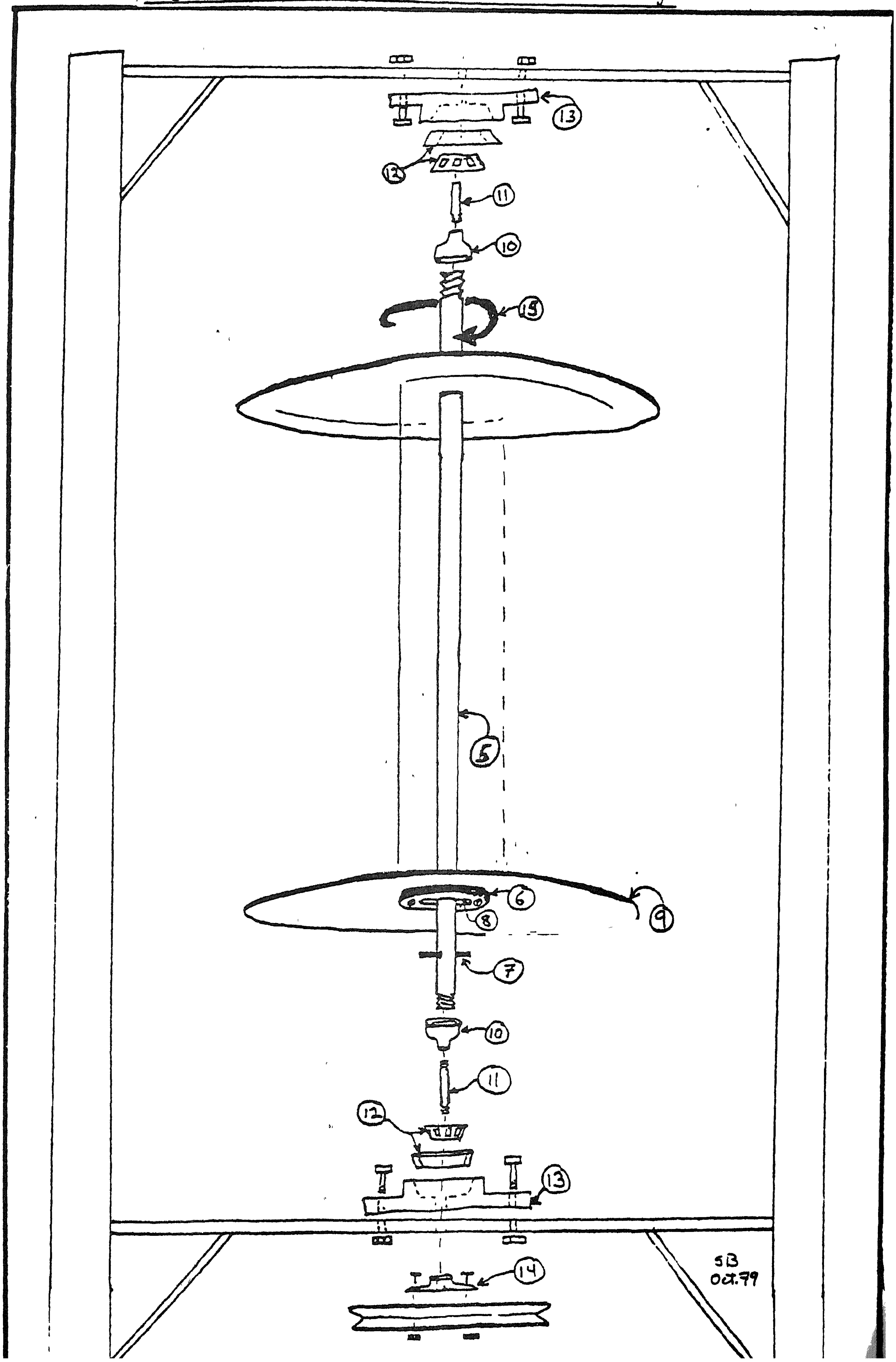


Fig. 88: Rotor with Top and Bottom Assembly



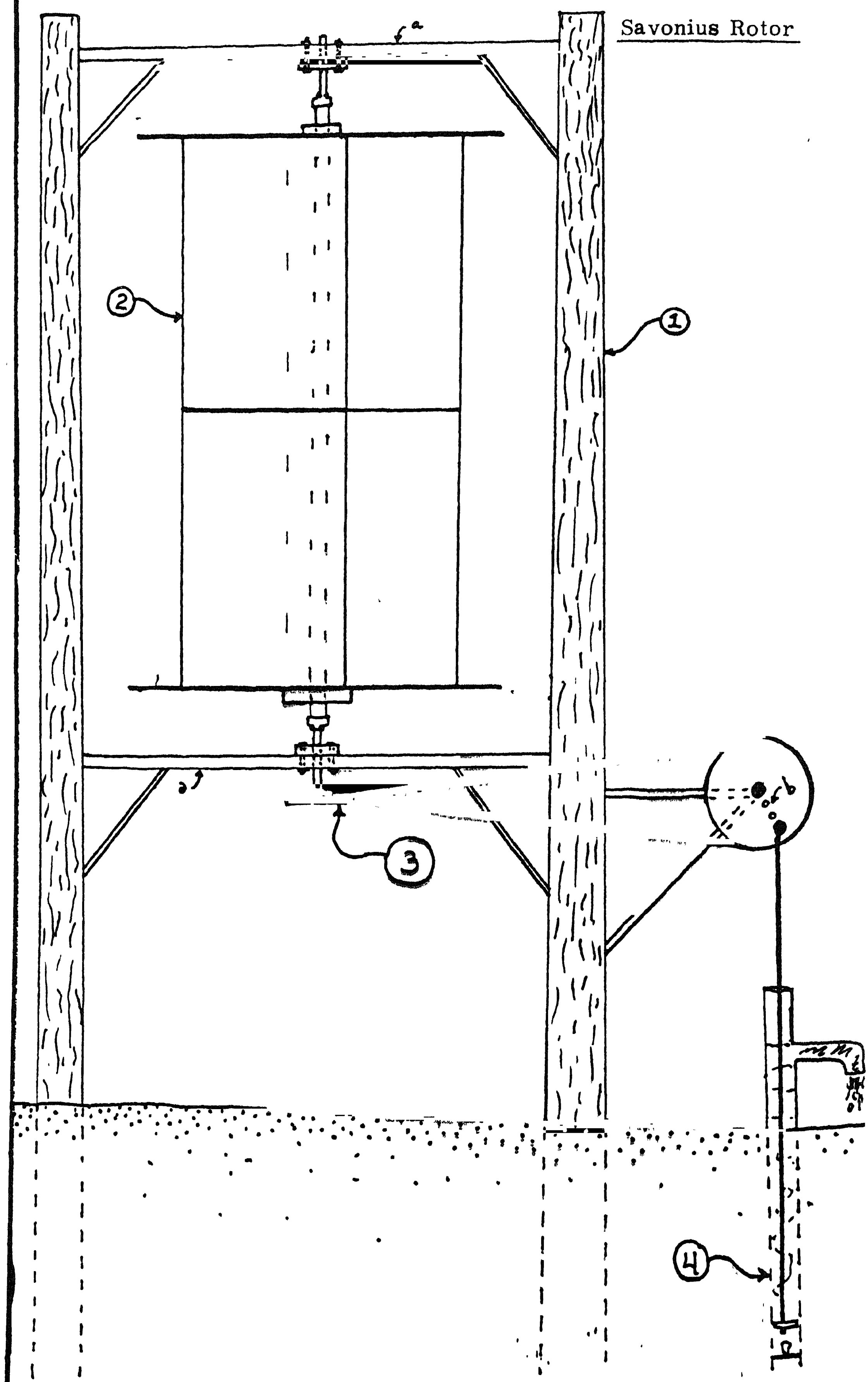


Fig. 87: Sunflower Power Co. - Savonius Rotor

The end disc serves to keep wind from spilling over the ends of the rotor, thus spilling power. A piece of hardwood (minimum (5 cm) 2" thickness) is attached to the bottom of the barrels or end discs. The central shaft is fixed to this by a pin in the central shaft (Fig. 88 No. 7) which fits into a slot in the hardwood. (Fig. 89 No. 8).

Top and Bottom Assembly of the Rotor :

The rotor shaft ends are threaded to the bell type reducers (Fig. 88 No. 10) 12.7 mm to 19.2 mm in size and galvanized. A 19.2 mm (3/4") ID water pipe (Fig. 88 No. 11) with outer diameter of 27.2 mm - 26.6 mm (1 1/6-1 1/18) fits through the bearing. Flanged bearing holders (Fig. 88 No. 12) are bolted to the cross beam of the support frame. A 19.2 mm (3/4") floor flange (Fig. 88 No. 13) has threads to accept the 19.2 mm (3/4") shaft (No. 11) and is connected with the V-belt pulley. The rotor is arranged such that the rotation is clockwise when viewed from above so that the pipe threads do not become unscrewed.

Power Transmission :

Power is transmitted from the rotor shaft to the pump via two V-belt pullies. The V-belt pulley at the bottom of the rotor shaft reduces speed through a U belt which is twisted 90 to a second V-belt pulley which is drilled to provide the eccentricity for pumping. Several strokes may be chosen by drilling at different radii on the pulley (b in Fig. 87). A 3:1 reduction has been found to be successful with a 5.08 mm (2") pump cylinder at a 6-8 m water level (stroke 2-7 cm).

Pump :

A conventional piston pump of 38 to 75 mm ($1\frac{1}{2}$-3") diameter is used with PVC cylinders and leather cup to seal the pump piston. However new plastic cups which appear more effective can also be used (available from Vidren Co., P.O. Box 7160, Amarillo, Texas 79109, U.S.A.). A foot valve is used to allow the water to flow in one direction.

Tower Frame :

A wooden pole "H" frame with 101.6 x 101.6 mm (4" x 4") bearing support members is used (a in Fig. 87). A lighter weight frame of similar design may also be used if guy wires are utilized.

Operating Data :

Pump - piston pump of 38 mm-76 mm ($1\frac{1}{2}$"-3") diameter
Discharge of a two-drum Savonius rotor in average windspeed of 16-19 km/hr ·

Output	Head
litres/hr	m
1135-1154	3.05
568-757	6.10

Conclusion ·

This plan is flexible and allows various options in the building process according to available skills and materials. The V-belt size and pump diameter can vary to accommodate the well depth and windspeed.

The Sunflower Power Company, Inc., welcomes any enquiries concerning this plan.

Reference :

1. A plan describing how to build a Savonius rotor wind turbine for pumping water. Oskaloosa, Sunflower Power Co., Inc., Leaflet, 7 pages.

CAT WINDMILL

Institutional Affiliation :

Centre for Alternative Technology,
Machynlleth Powya,
WALES.

Background :

A plan for constructing a Savonius rotor for water pumping was prepared by John Eyles for the Centre. The plan is described below.

Application :

Water pumping for low and medium lift applications.

Type :

Vertical axis, multidirectional, metal drum, Savonius rotor. (Fig. 89)

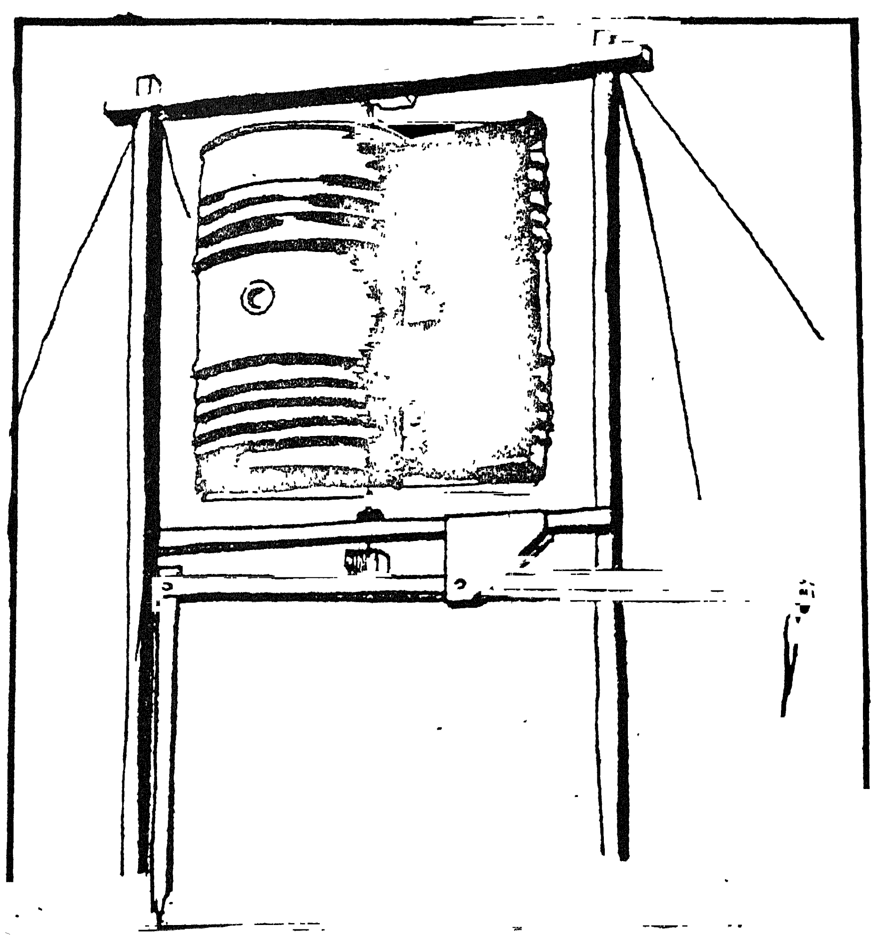


Fig. 89: CAT's Low-Speed Savonius Rotor

Suitability :

The windmill functions well in windspeeds of 8 kmph.

Design Features :

Rotor Assembly :

The rotor is made out of an oil drum (86 cm x 51 cm)

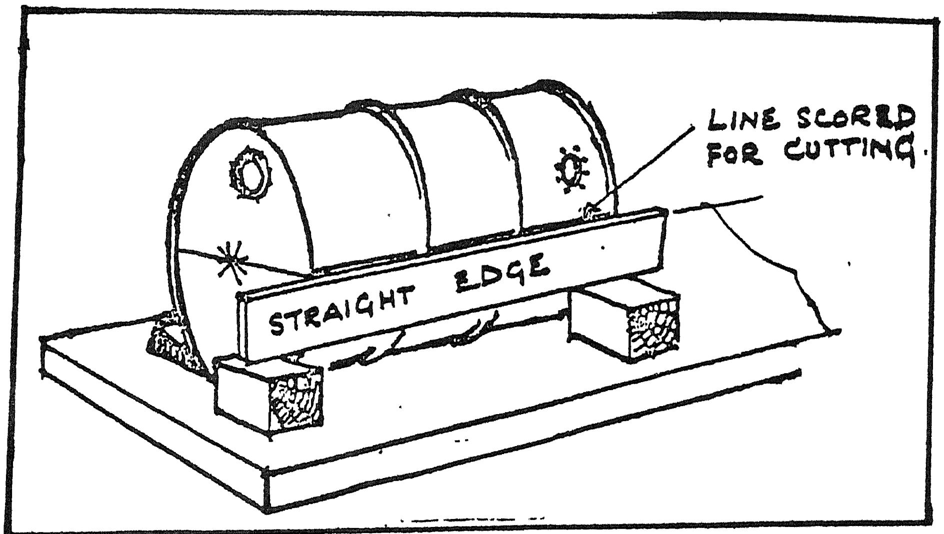


Fig. 90· Cutting the oil drum

As shown in Fig. 90 the drum is kept on its sides and chalk lines made along the diameters and along the sides, so that the drum is cut exactly into two halves.

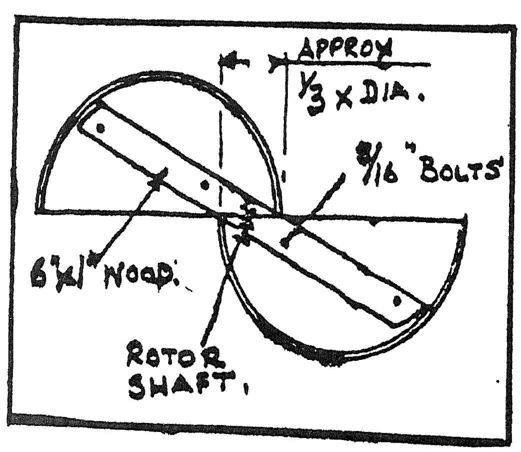


Fig. 91: Rotor Assembly - Top View

For joining the two halves two pieces of 2.5 cm x 15.3 cm (1" x 6") timber are used as shown in Fig. 91. The overlap of the drum halves can be about 1/3 of the diameter. A hold

of the size of the shaft is bored in the centre of each of the 2.5 cm x 15.3 cm.(1" x 6") board. These boards are bolted to the drum with 8 mm x 38 mm (5/16" x 1½") bolts. The shaft which is 2.13 m (7') in length and 25.4 mm (1") outer diameter is passed through the rotor leaving about a foot at the top and at least two feet at the bottom. The shaft is fixed to the rotor by clamping a U-bolt round the shaft to a short length of angle iron and screwing it further to the 2.5 cm x 15.3 cm (1" x 6") board.

Balancing :

Though the rotor speed is slow, the height of the drum cells for proper balancing.

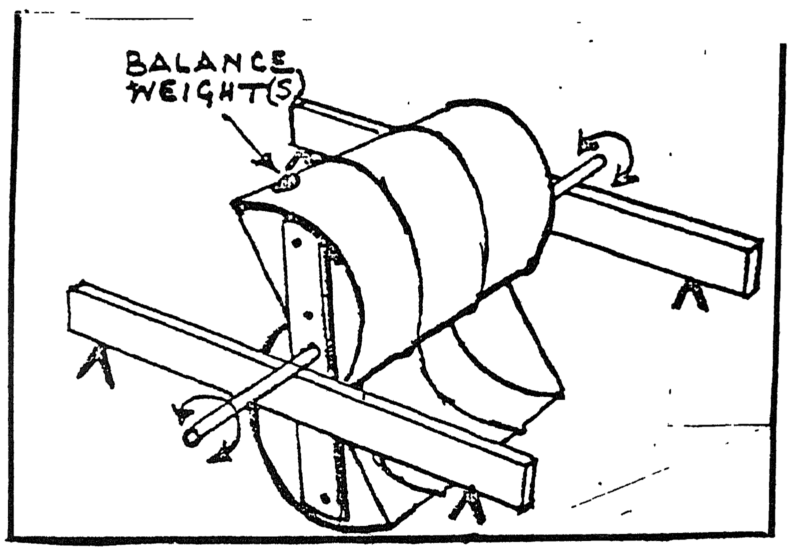


Fig. 92: Balancing

As shown in Fig. 92 two 19.2 mm (3/4") boards clamped on the edge of two saw-stools are made sure they are exactly levelled. The rotor is placed between them and rolled to find the light side. Bits of metal or cellotape on washers are bolted to the lighter side till balance is achieved.

Power Transmission :

A small plunger is activated by means of a cam-driven rocker arm. (Fig. 93). The cam/swash plate is a block of hardwood (mahogany) 10.2 x 10.2 x 10.2 cm (4" x 4" x 4") cut at an oblique angle and bored to go over the edge of the shaft. The rocker arm is made of two lengths of 5.1 x 2.54 cm (2" x 1")

screwed in the middle on to a foot length of 6.4 cm (2½") timber, making a long fork. The follower, a 5.1 cm (2") outer diameter Ball Race is bolted into the end grain of the 6.4 cm (2½") timber, and the whole mounted within two 1.27 cm (½") plywood trunnions which are then screwed to the frame in such a position that the ball race is in contact with the oblique face of the cam during its full rotation. The rocker magnifies the throw of the cam to about 6.4 cm (2½") stroke at its end. The other end of the rocker arm is long enough to allow a reasonable size of counter-weight.

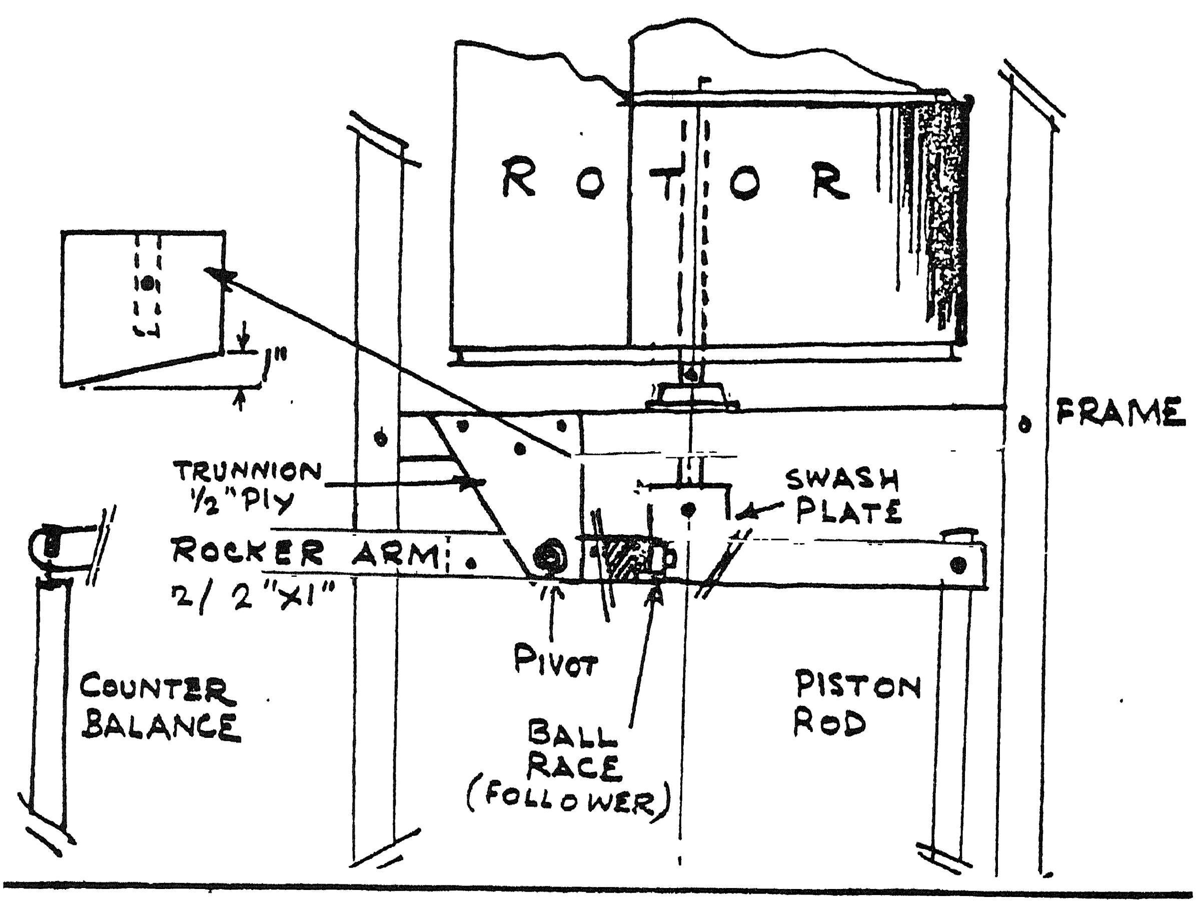


Fig. 93· Drive Mechanism

Tower :

The support frame is in the form of a free-standing triangulated structure as shown in Fig. 94.

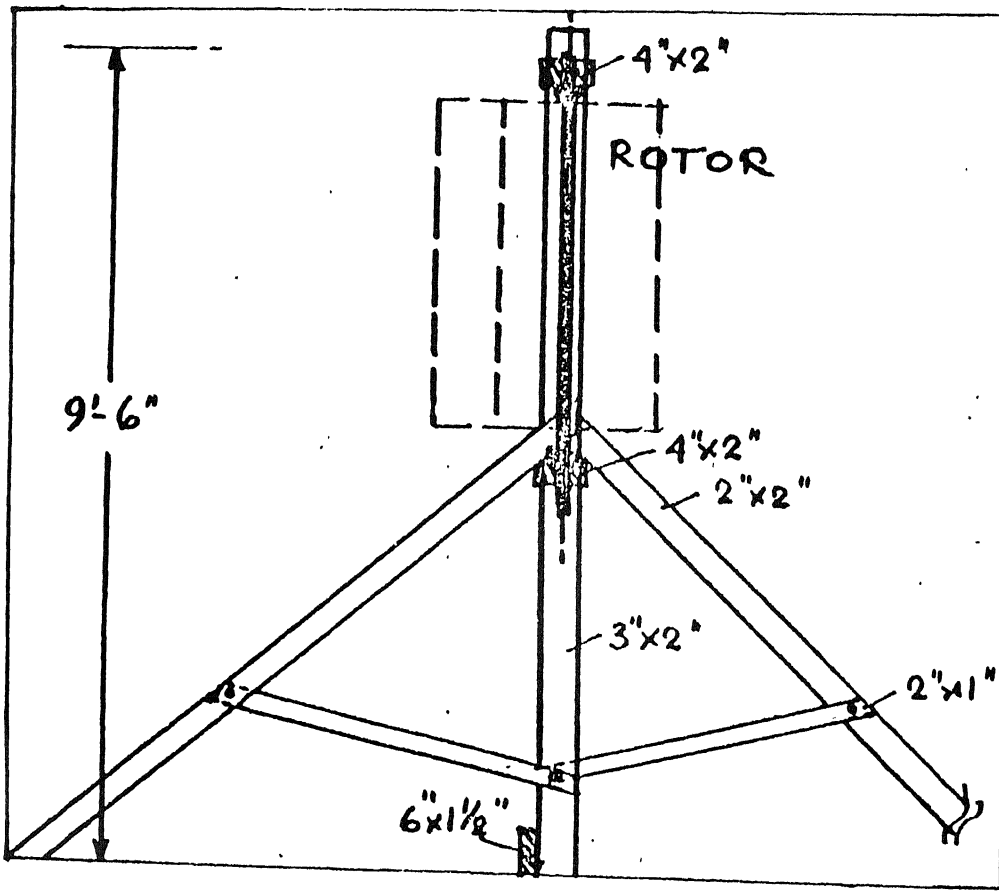
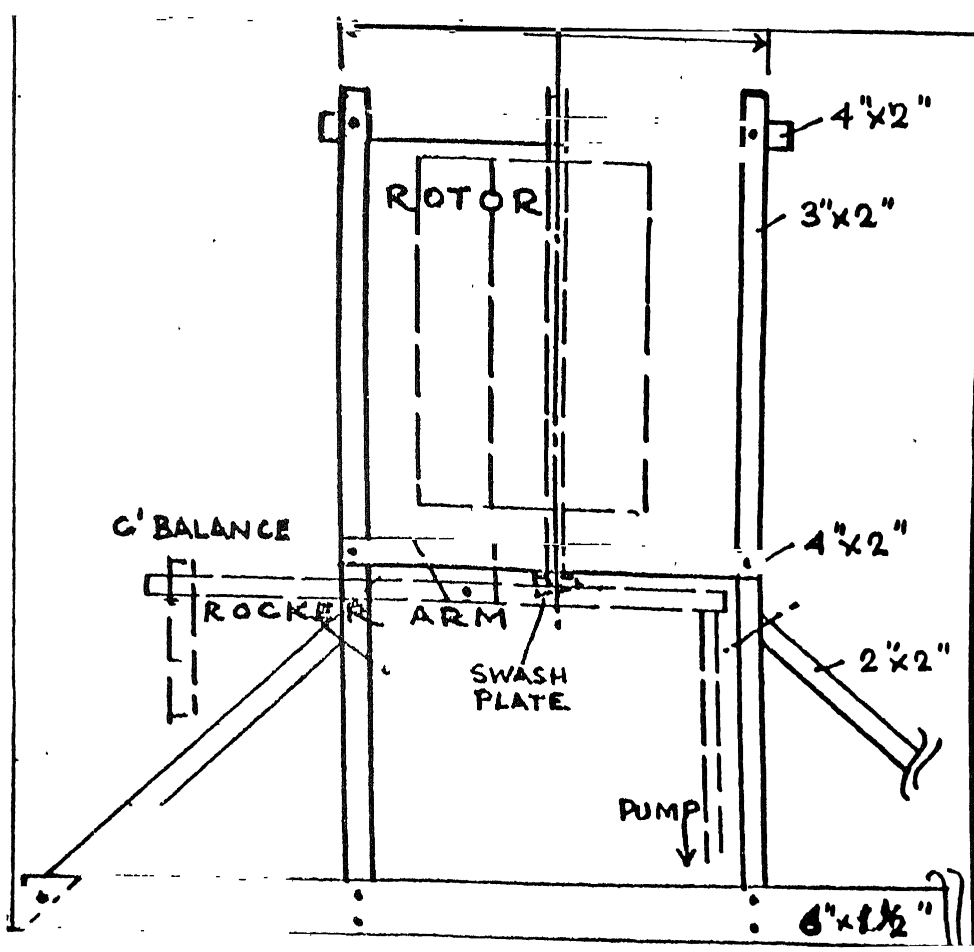


Fig. 94· Support Frame



Conclusion :

The performance data of the windmill is not known. However, the design is simple and can be easily fabricated at village level.

Reference :

1. D.I.Y. PLAN3 - Pumping Windmill (Savonius) by John Eyles. Machynlleth, Centre for Alternative Technology. Leaflet 6p.

VITA WINDMILL

Designer :

Josef A. Kozlowski.

Institutional Affiliation :

Volunteers in Technical Assistance,
360 Rhode Island Ave.,
Mt. Rainier, Maryland 20822,
U.S.A.

Application :

Pumping water from borehole.

Type :

Two-stage (double), metal drum Savonius rotor. Fig. 95.

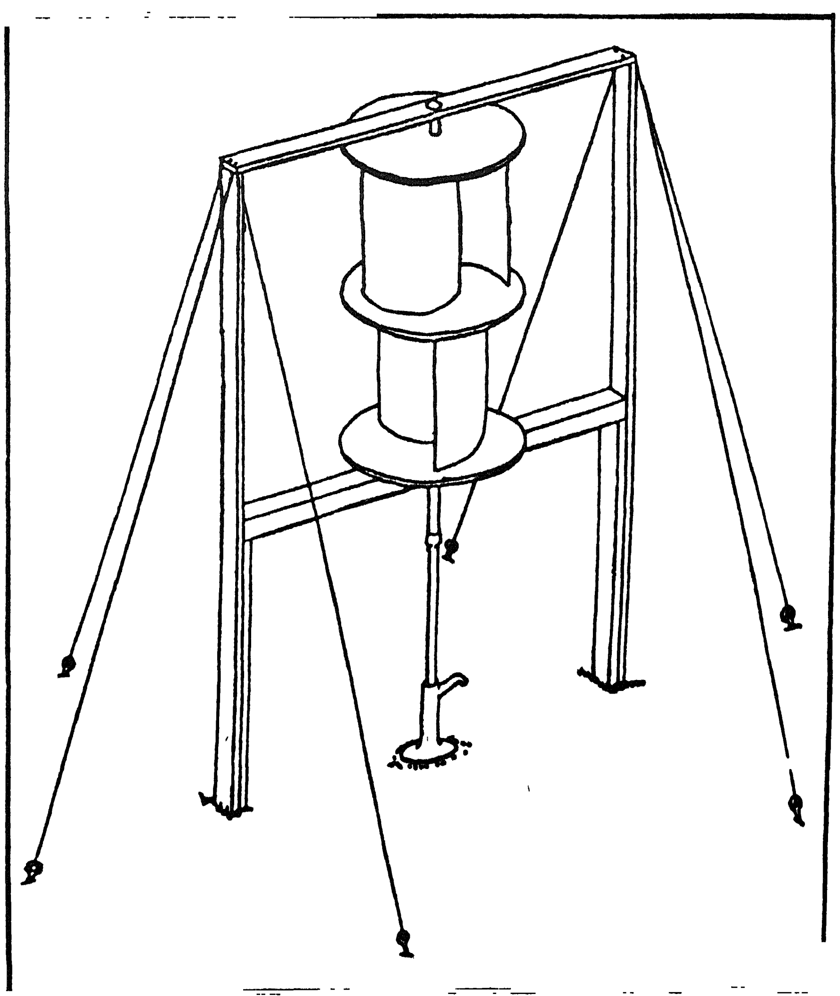


Fig. 95: Two-stage S-Rotor

Design Features :

Rotor Assembly :

The rotor consists of two 45 gallon oil drums (86 cm x 51 cm) each split into half, the bases removed and the two drum havles positioned at 180 to each other and screwed between plywood discs of 115 cm (46") diameter and 1.25 cm (½") thickness. (Fig. 96)

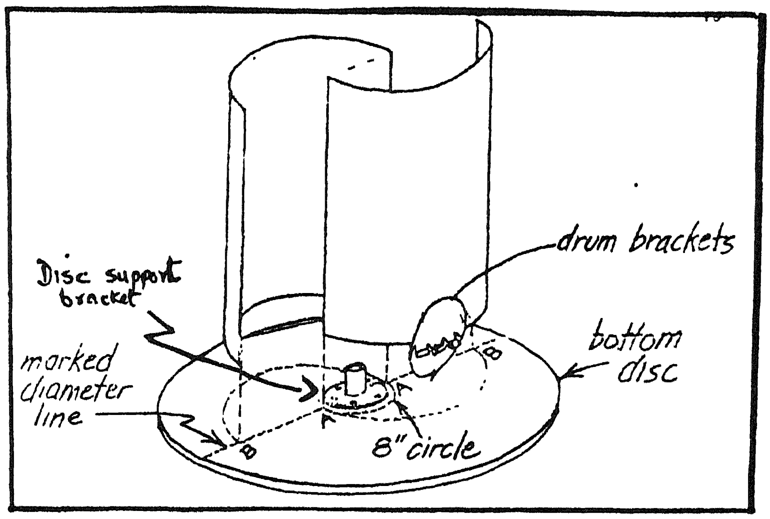


Fig. 96· Half-drum and disc for Assembly

Three disc support brackets attach the plywood disc/ half drum assembly to a pipe shaft. End pieces of the top and bottom of the rotor shaft each rest in a roller or ball bearing attached to a horizontal support beam. The lower bearing which must absorb both axial and radial forces is a sealed, self-adjusting flange ring roller bearing. The lower bearing which must absorb both axial and radial forces, is a sealed self-adjusting flange ring roller bearing. The upper bearing can be of any type which is sealed the correct way. The bearings fasten to the top side of each side of each beam at the central point as shown in Fig. 97.

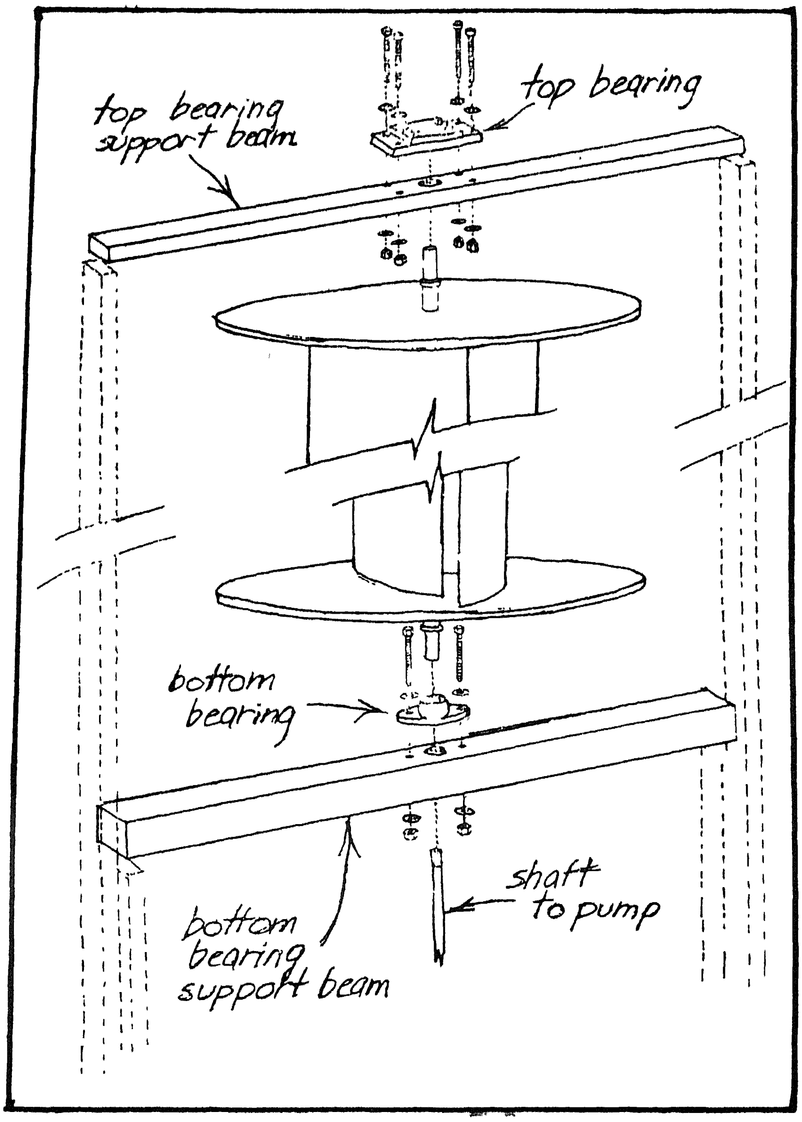


Fig. 97: Bearing Support Beams

Power Transmission :

A direct rotor/pump hook-up with an extension piece connecting the S-rotor shaft to the shaft extending down the borehole to the rotary pump, pushes water up the borehole by a screwlike mechanism.

Pump :

The connecting shaft is attached to a positive displacement rotary borehole (submersible) pump. The vanes of the rotor are set in the same direction as that in which the mono-pump operates.

Support Frame :

As shown in Fig. 98 there are two tall 5 x 10 cm (2 x 4") wood-frame supports which sink into the ground 2 m (6') apart from each other. There are two shorter pieces of 5 x 10 cm (2 x 4") wood right up, next to the inside surface of each of the taller supports. The bottom bearing support beam rests on the top ends of the shorter supports. The top bearing support beam rests on the top end of the tall supports.

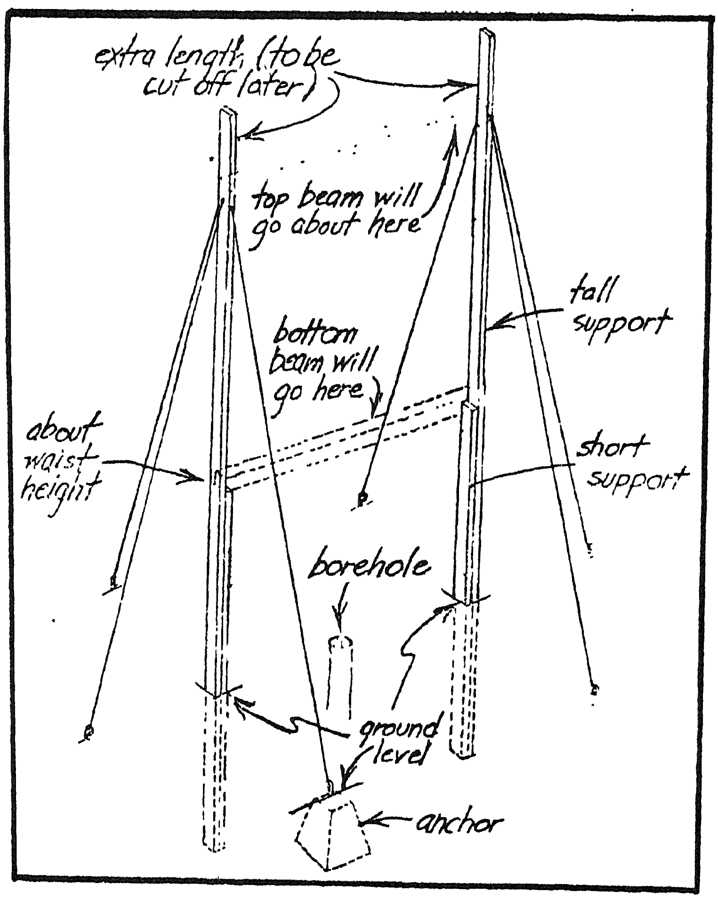


Fig. 98: Rotor Frame

6 guy wires which stabilize the rotor frame are attached from the top of the tall vertical frame supports to the loops of the anchors buried underground.

Braking :

Braking is manual, by pressing a piece of wood into the lower V-belt gear, at high wind velocities there is a danger of imbalance.

Conclusion :

The construction of the windmill makes use of sufficient cutting, drilling and welding. It may be slightly difficult to construct it in rural conditions. A machine shop is required for the assembling of the rotors.

Detailed building instructions are given in Ref. 1.

Reference :

1. Savonius Rotor Construction: Vertical Axis Wind Machines From Oil Drums by Josef A. Kozlowski. Maryland, VITA, 1977. 53p.

IISc WINDMILL

Designers :

Dr. S.P. Govind Raju, R. Narasimha and others.

Institutional Affiliation :

Indian Institute of Science,
Dept. of Aeronautics,
Bangalore 560 012,
INDIA.

Background :

Two prototypes were designed and fabricated during June 1975-Jan. 1978. They are largely similar but the second prototype has a slightly different sail profile and rotor support structure.

Application :

Lifting water from wells for domestic use or for minor irrigation.

Type :

Vertical axis windmill with sail type-Savonius rotor. (Fig. 99)

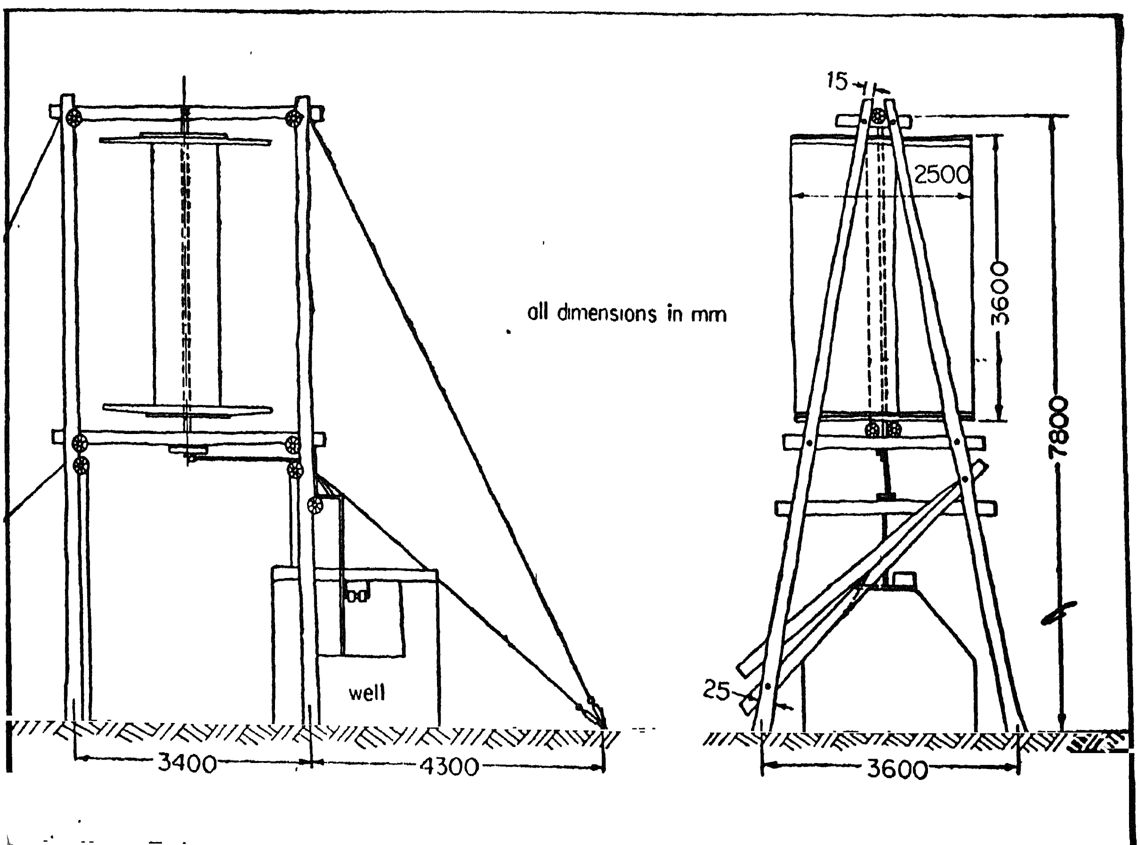


Fig. 99. Configuration and Major Dimensions of IISc Prototype

Suitability :

Areas prone to multidirectional winds ranging between 10-20 kmph.

Design Features :

Rotor Assembly :

The rotor is of Savonius type and consists of a vertical shaft in the form of a galvanised steel pipe with suitable welded end fittings. The shaft is supported by a simple self-aligning brass bush at the top and by a ball bearing at the bottom. The bottom end of the shaft can carry a brake/power take-off drum and an end-crank for driving a pump.

Near the end of the shaft are welded fittings to which can be bolted wooden end-plates of built-up construction, using planks of 12 mm and spars and ribs of 25 mm nominal thickness. As shown in Fig. 100 these end-plates each have a central structural part to resist loads exerted by wires strung vertically between them. Extensions to the central parts in the form of plywood sheets supported by a rib complete the end-plate.

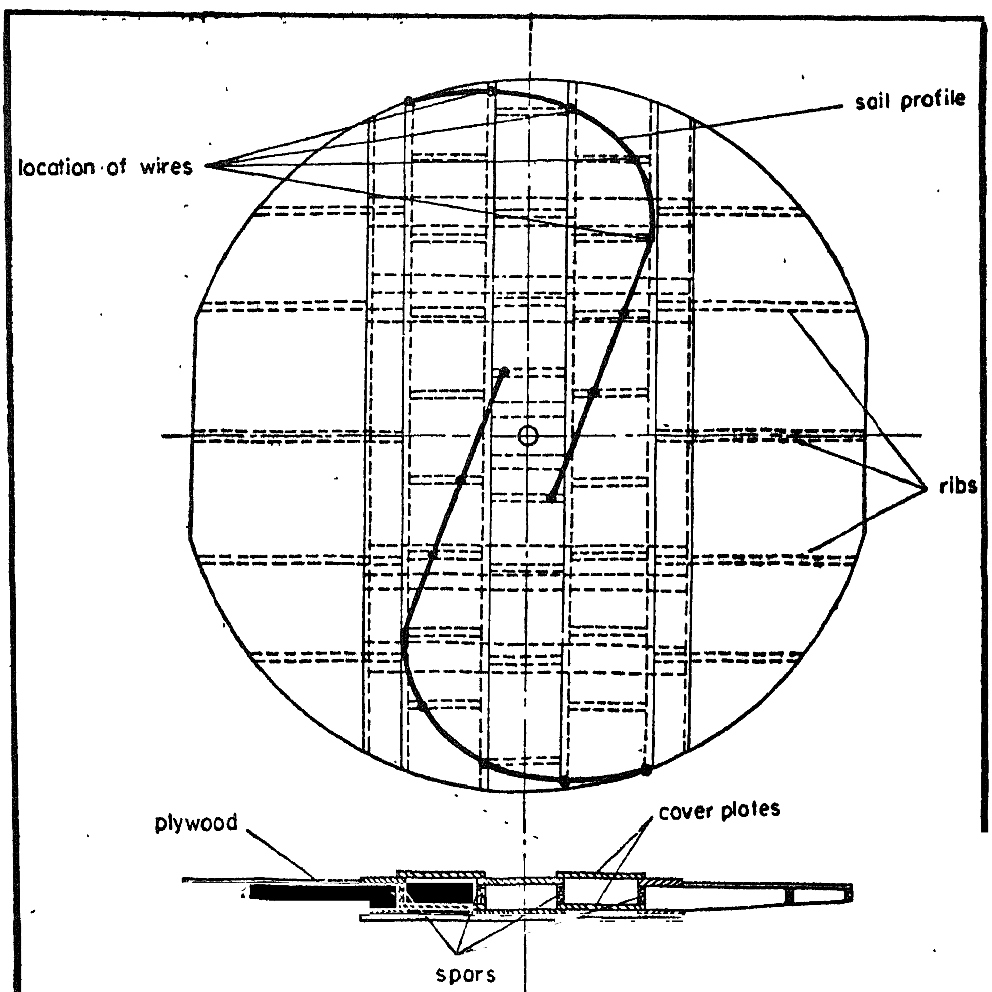


Fig. 100: End-plate Assembly Showing Sail Geometry

Sail Assembly :

The sails, two in number, are made of jute canvas. They are attached to the wires by threading the wire through loops stitched to the canvas. Each sail incorporates a total of five loops, 4 for the first four wires, counting from the leading edge, and the last one at the trailing edge. This leaves 3 wires touching, but unattached to each sail. Skirts, about 10 cm wide at the edges near the end-plates, provide a seal there and allow for any error and/or shrinkage of the fabric after installation. After installation, the sails and skirts are painted with coal tar to make them non-porous and weather-proof.

The wires strung between the end-plates (16 in all) form the support system for the sails which form the aerodynamic surface of the rotor. The wires pass through ribs in the end plates from one side and are clamped on the other side. During installation, the wires are so clamped that there is play at their midpoint of about 15 cm.

Safety Device :

Attaching sails to their supporting wires incorporates a safety measure during excessive winds. Wires at the trailing edge have twisted joints just below the end-plate. Each twisted joint unwinds at a definite and predictable tension in the wire. During high wind, the corresponding sails open out, being held by four wires near the leading edges. This reduces the rotor speed as well as unloads the structure.

Power Transmission :

As shown in Fig. 101 the transmission consists of the end crank, connecting rod, bell crank and the operating rod (made of GI pipe of 12 mm size). The connecting rod attached to the end crank of the shaft just below the rotor activates the bell crank which in turn moves the pump via the operating rod.

The transmission conveys power from the rotating shaft below the rotor to the oscillating pump operating lever at the pump, thus conveying power over a distance of 15 m or more.

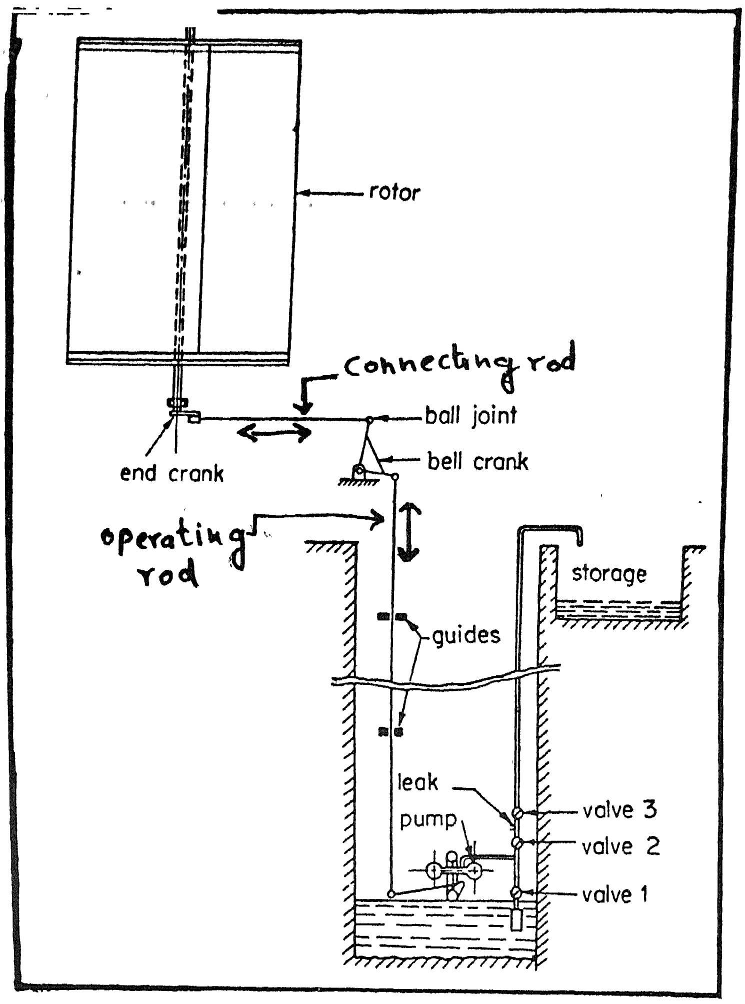


Fig 101: Schematic Layout of IISc Wind Pump

Pump :

A positive displacement pump is used which consists of the casing of a pneumatic tyre of 35 cm diameter blocked by two discs (one at each bead) thus creating an enclosed volume (Fig. 102). The oscillating pump operating lever at the pump causes the displacement between the discs. The relative displacement between the discs changes the enclosed volume and is used as the pumping chamber of a positive displacement pump. The pump incorporates an unloading device in the form of a small leak and a check valve in the delivery pipe just after the delivery valve.

The level of water in the open well is 10 m below ground level and the pump whose suction is ilimited to 3 m is located just above water level.

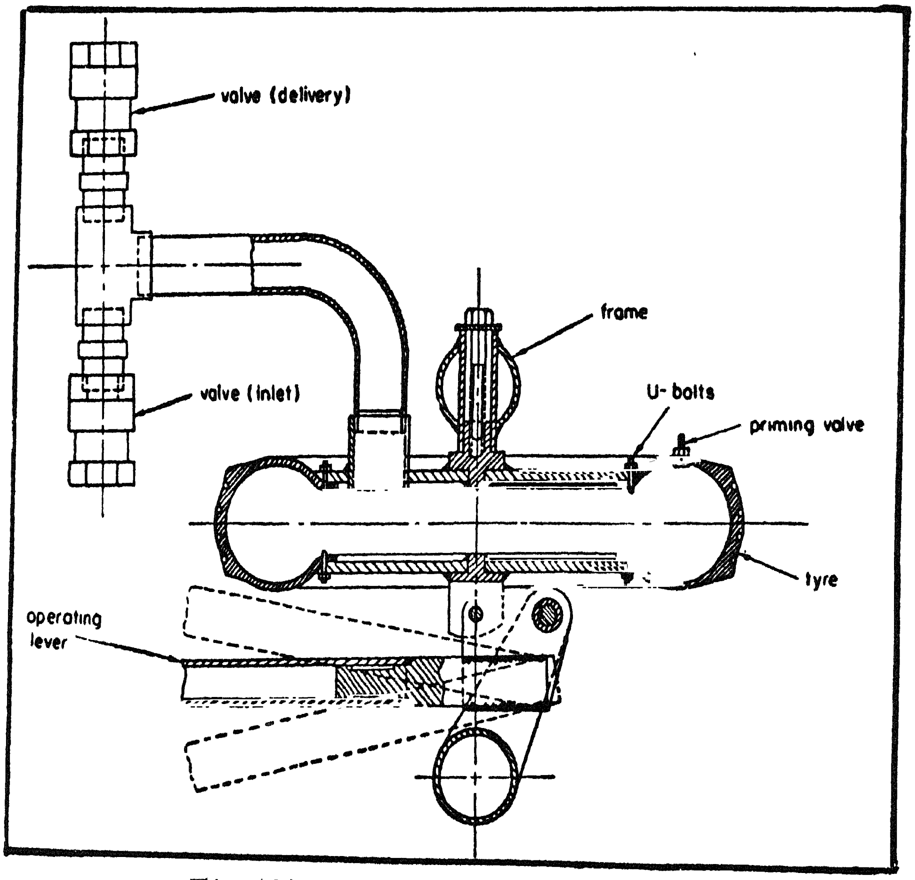


Fig. 102: Cross-section of the Pump

Tower :

Each windmill consists of 2 A-frames spaced apart by two connecting beams, with the rotor, supported between the beam centres as shown in Fig. 99. The lower parts of the A frames are triangulated by diagonal members. Guy wires are used to add strength and stiffness to the structure.

Prototype 1 uses timber of 5 cm x 10 cm nominal size and boards of 2.5 nominal thickness.

Prototype 2 uses casuarina poles 20 to 25 cm dia. near the base, tapering to about 15 cms at a height of 10 m.

All the joints in the wood are by mild steel bolts of 12 mm diameter.

Unloading Device :

A small leak and check valve in the delivery pipe is incorporated just after the delivery valve. This eases the starting of the windmill by reducing the torque demand of the pump for low rotor speeds.

Operating Data :

Area swept by the sail : 8 m^2
Pump: Positive displacement type (made of pneumatic tyre blocked by 2 discs)
Static head: 20 m
Delivery: 1 litre per cm stroke (stroke adjustment by variable arm crank provided)
System efficiency: 11% @ 10 kmph windspeed.

Conclusion :

The windmill mainly uses solid wood (tower end plates) and metallic parts (main shaft, the transmission and the pump). It is adaptable to local conditions with modest variations in dimensions, materials and skills.

The second prototype constructed at village Ungra (about 100 km from Bangalore) began operating in Sept. 1977. In 1978, it was delivering an average of around 2500 litres of water per day.

New sails, including stoppers and modifications in the sail support system, have been incorporated.

The knowledge and engineering drawings can be obtained from the designers.

Reference :

1. A Low-Cost Water Pumping Windmill Using a Sail-Type Savonius Rotor by S. P. Govindaraju and R. Narasimha. Report 79 FM2, Indian Institute of Science, Dept. of Aeronautics, Bangalore, 1974. 94p.

4

NON-CONVENTIONAL WIND PUMP DESIGN

FLAPPING VANE WIND PUMP

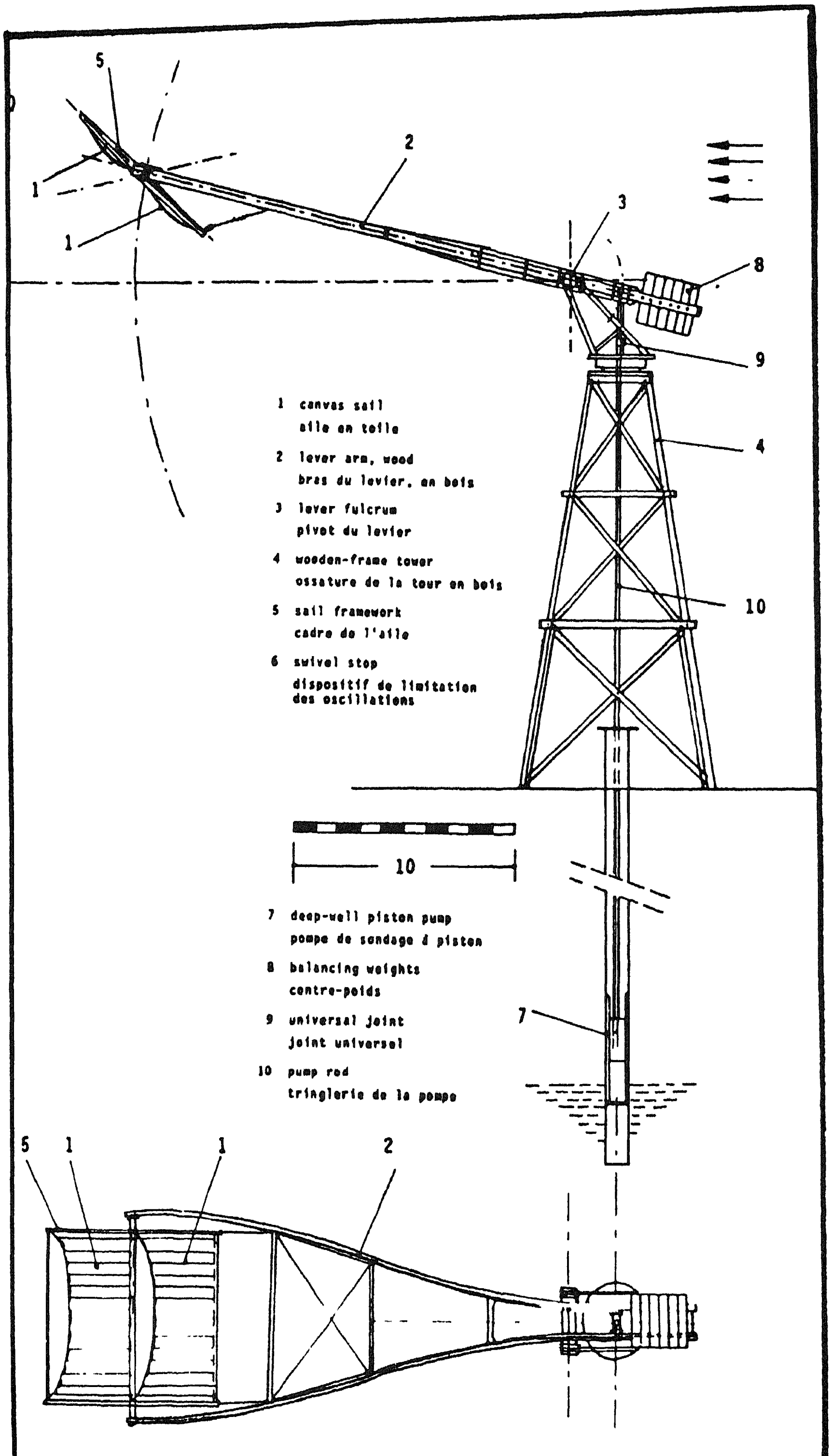


Fig. 103: Flapping Vane Wind Pump and its Components

Contact :

Dipl - Ing. Peter Bade.

Institutional Affiliation :

Institute for Wasserbau und
Nasserwirtschaft,
Technische Universitat Berlin,
Strabe des 17 Juni 1935,
D-1000,
BERLIN 12.

Background :

The flapping vane pump prototype was built in Berlin,

Application :

Pumping water from deep wells.

Typing :

Flapping vane, multidirectional wind pump. (Fig. 103)

Design Features :

One or two cloth vanes are rotably mounted on the end of a long swinging lever so that they can swivel freely (Fig. 104). The vane can swing freely about its axis within the range of an upper and lower angular stop. In order to protect the vane bearings from excessive shock loading when the vane flaps, the angular stops are fitted with a shock absorber.

The swinging lever is rotably mounted in a fulcrum so that the swinging lever can move up and down about this point. The lever fulcrum is mounted on a pedestal which can rotate on top of the tower in order to allow the vane to automatically orient itself to the direction of the wind. The height of the mast is kept such that it does not touch the ground at the maximum angular position and can always work in an undisturbed wind current. Weights attached to the lever arm at the end remote from the vane serve to keep the system in static equilibrium.

At a distance from the fulcrum is the point of engagement of a connecting rod which acts on a thrust rod, through a universal joint.

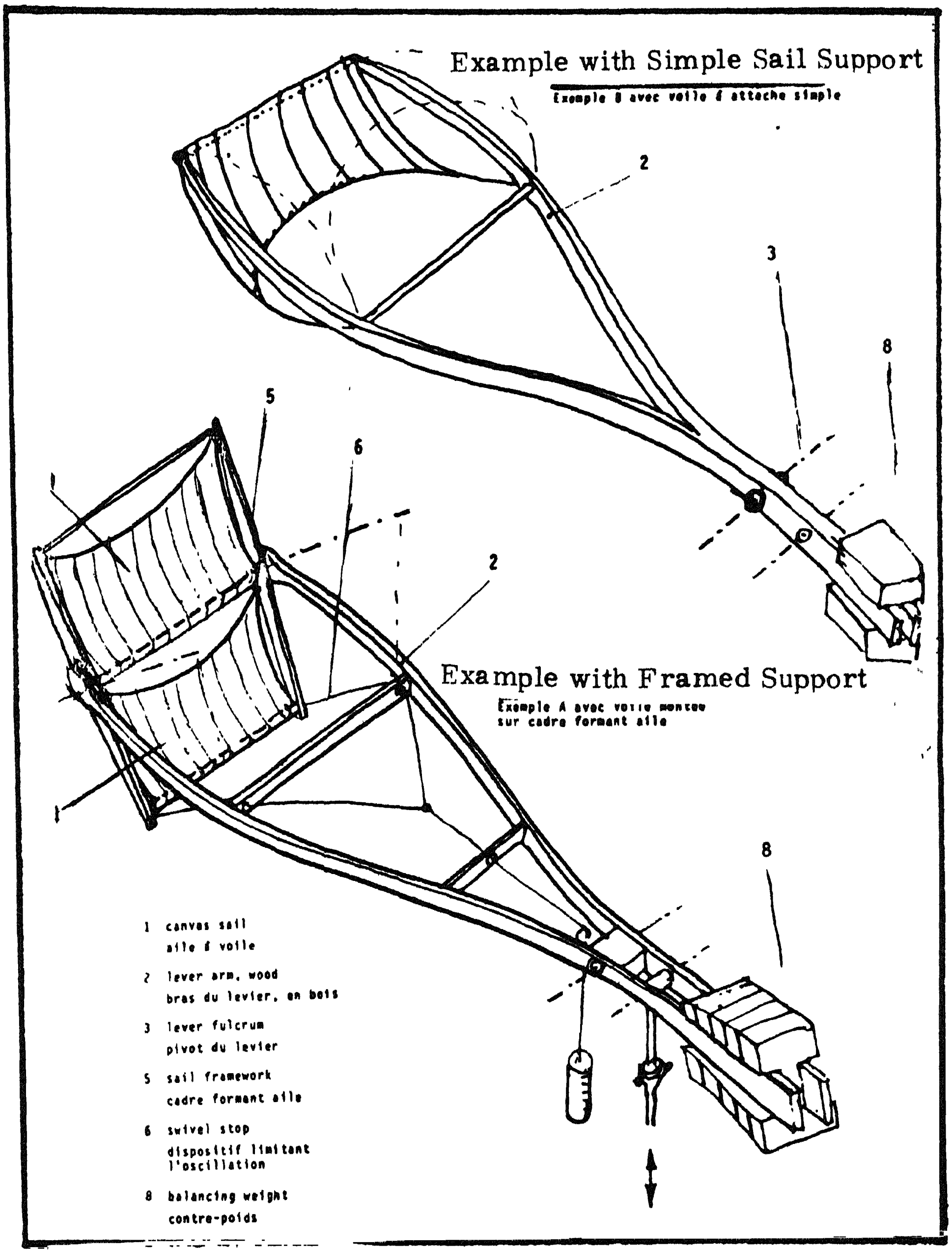


Fig. 104: Sail Assembly

Power Transmission :

Action of the wind on the vane alternatively depresses and lifts the lever arm with resultant power applied to the reciprocating rod which operates the pump.

Pump :

Although the flapping vane wind pump has been designed for use with deep-well piston-type water pumps (both single and double-acting pumps can be used), it may be adapted to

diaphragm pumps or to a crankshaft flywheel to produce rotary motion.

Operating Data :

Vane Area	29 m^2
Lever Arm	20 m
Piston diameter	0.143 m
Pump Lever	1.2 m
Mean Pump Stroke	0.6 m

Performance :

Delivery height	Wind Speed	Discharge
40 m	16 km/hr	150 m^3/day

Conclusion :

This novel idea of water pumping has not yet been given full-scale demonstration, but the simplicity of operation and low-cost construction make it worthy of further consideration.

The design can be modified so that the main components such as vane, lever arm, mast and also the pump and rod can be made of simpler and well tried materials.

Reference :

1. 'Flapping-vane Wind Machine and Rod Piston Pump, an Integrated Delivery System for Large Well Depths and Small Flow Rates' by P. Bade. Appropriate Technologies for Semiarid Areas: Wind and Solar Energy for Water Supply. Berlin, German Foundation for International Development, 1975, p.71-82.

2. 'Flapping-vane Wind Machine' by P. Bade. Appropriate Technologies for Semiarid Areas: Wind and Solar Energy for Water Supply. Berlin, German Foundation for Water Supply, 1975, p.83-88.

COMMERCIAL WATER PUMPING WINDMILLS

	Manufacturer	Rotor dia. (m)	No. of blades/ Blade materials	Trans-mission	Cut-in wind speed (kmph)	Cut-off-wind speed (kmph)	Pump type
1.	AEROMOTOR, Div. of Valley Industries, P.O. Box 1364, Conway, Arkansas 72032, U.S.A.	6 sizes	18	Pitman gear	-	40	Piston-type. Pump in various sizes: dia 4-20 cm.
2.	AEROWATT, 37, rue Chanzy, 75011 Paris, FRANCE.	5 sizes 1.2 to 9.0	2 Al. alloy blades/ stainless steel/ protected steel	-	1	-	Centrifugal pump
3.	ATELIERS et CHANTIERS NAVAL de, Chalon-sur-Saone, B.P. 103, 71103 Chalon-sur-Saone, FRANCE.	3.05 to 6.1	Multibladed	Gear wheels + crank rod system	11	72	-
4.	GEBR BAKKER, Zevenpelsen 25, 8651 BT 1st, HOLLAND.	2.1 and 2.7	4 Wood and steel	Gear wheels	-	-	-
5.	BOSMAN Waterbeheer-sing en milieuverbetering BV, P.O. Box 3701, 3265 ZG Piershil, HOLLAND.	4 sizes 3-5.5	Multibladed, galvanised steel	-	-	-	-

Manufacturer	Rotor dia. (m)	No. of blades/ Blade materials	Trans-mission	Cut-in wind speed (kmph)	Cut-off-wind speed (kmph)	Pump type
6. BOWJON,	2.3	4	-	10.17	48	Compressor and air injection pump
2829 Burton Ave.,						
Burbank, CA 91504,						
U.S.A.						
7. CLIMAX Windmills	5 sizes	Multibladed	Gears			Piston type
(Pty.)Ltd.,	1.8			10.44	58	
General Hertzog Rd.,	2.4			6.48	50	
Box 20244,	3			11.16	43	
1934 Peacehaven,	3.7			13.68	40	
S. AFRICA.	4.3			15.4	40	
8. DEMPSTER,	5 sizes	Multibladed,	-	8	79	Piston type dia.
INDUSTRIES,	1.8 to 4.3	galvanised				5-10 cm
P.O. Box 848,						
Beatrice, NB 68310,						
U.S.A.						
9. ERNEST HAYES (N.Z.)	3 sizes		Crank	6		Piston type
Ltd.,	1.8	8			40	
Box 23-042,	2.5	16			32	
789 Main South Road,	2.6	20			32	
Christ Church,						
NEW ZEALAND.						
10. THE HELLER-ALLER	4 sizes		Pitman	-	-	Piston type
CO.,	1.8	20	gear			
Napoleon, Ohio 43545,	2.4	36				
U.S.A.	3.0	30				
	3.7	32				
		Galvanised steel,				
		greg cast iron				

Manufacturer	Rotor dia. (m)	No. of blades/ Blade materials	Trans-mission	Cut-in wind speed (kmph)	Cut-off-wind speed (kmph)	Pump type
11. B. HERTOG, Julianastraat 10-14, 2751 GD Moerkapelle, HOLLAND.	3	4	Gear wheels	14	43	Centrifugal type
12. EOLIENNE "HUMBLOT", 8, Rue d'Alger, Coussey, 88300 FRANCE.	9 sizes			9	36	Piston type
	1.75	6-8-12-16				
	2	12				
	2.25	12				
	2.5	12				
	2.75	12				
	3.5	16				
	4, 5, 6	16				
13. FABRICA DE IMPLE-MENTOS AGRICOLAS, Wortigueria 1890, Buenos Aires, ARGENTINA.	6 sizes 1.83 m to 4.88 m	18	Pitman gear	-	-	Piston type
14. H.J. GODWIN LTD., Quenington, Gloucestershire, ENGLAND.	7 sizes 1.8 m to 5.49	18	Gear box	-	-	SL type syphon pumps for shallow wells; FL Force heads with deep well cylinders
15. SYDNEY WILLIAMS & CO. (Pty) Ltd., Constitution Rd., Dulwich Hill, Sydney N.S.W. 2202, AUSTRALIA. (11 MODELS)	11 sizes 2.4 to 9.1	-	-	-	-	Draw plunger pumps; flush-end pumps; syphon pumps.

Manufacturer	Rotor dia. (m)	No. of blades/ Blade materials	Trans-mission	Cut-in wind speed (kmph)	Cut-off-wind speed (kmph)	Pump type
16. SPARCO (Denmark), C/o Enertech, P.O. Box 420, Norwich, VT 05055, U.S.A.	1.25	2 Cast aluminium		9	-	
17. SOUTHERN CROSS, Teewoomba Foundry Pty. Ltd., P.O. Box 109, Toowoomba, AUSTRALIA 4350.	5 sizes	Multi bladed	Gear wheels	14	52	Piston type various dia.
18. SOUTHERN CROSS (Contd.)	5.2 6.4 7.6	Multibladed galvanized steel	Direct acting	14	52	Piston type various dia.
19. TEN FA IRON WORKS, 188, Kung Fu Road, Chin-Li Chen, Tainan Hsien, Taiwan, REPUBLIC OF CHINA.	4 sizes	6	-	-	-	
20. VESTAK, Postbus 3, Isando TVL 1600, REP.OF S.AFRICA.	3.0	16	Cam and roller	10	10-66 (adjust-able)	Piston type dia. 50 mm

Manufacturer	Rotor dia. (m)	No. of blades/ Blade materials	Trans-mission	Cut-in wind speed (kmph)	Cut-off-wind speed (kmph)	Pump type
21. WADLER MANU-FACTURING CO., Rt. 2, Galena, KS 66739, U.S.A. (4 MODELS)	Savonius Rotor	Blade material - aluminium	Direct drive	36	None	Water aeration system
22. WAKES & LAMB Millgate Works, Newark Notts, ENGLAND.	4.9	6	belt/gear wheel	2-3	-	Different types

APPENDICES

I. Glossary

II. Conversion Tables

III. Important Formulae

APPENDIX I.

GLOSSARY

Aerofoil	the blades of the windmill designed to provide a desired reaction force when in motion relative to the surrounding air.
Anemometer	a device for measuring windspeed.
Axis	an imaginary line passing through the centre of a body about which the body rotates.
Axle	a supporting member that carries a wheel and either rotates with the wheel to transmit mechanical power to or from it, or allows the wheel to rotate freely on it.
Bearing	a machine part that supports another part which rotates, slides or oscillates in or on it.
Bevel gear	one of a pair of gears used to connect two shafts whose axes intersect.
Bore	the interior diameter of a tube.
Bore-hole	a deep vertical hole.
Brace	to fasten tightly.
Brazed	joined by melting metal.
Cam	an eccentric projection on a revolving shaft, shaped so as to give some desired linear motion to another part.
Cantilever	a beam or member securely fixed at one end and hanging free at the other end.
Centrifugal pump	a pump having vanes that rotate in a casing and whirl the fluid around so that it acquires sufficient momentum to discharge from extremities into a volute casing which surrounds the impeller and in which the fluid is conducted to the discharge pipe.

Chisel	a tool with sharpened edge at one end used to cut, pare, gauge, engrave or shape wood.
Corrugated	having parallel grooves and ridges.
Crank	an arm on a shaft for communicating motion to or from the shaft.
Crank-shaft	the main shaft of the windmill which carries a crank or cranks for attachment of connecting rod.
Cut-in-wind-speed	speed at which the windmill begins to produce useable output (this is not the start-up wind-speed, which is the speed required to begin rotation of the blades).
Cut-off-speed	the windspeed at which a windmill is designed to shut off to prevent damage from high wind.
Diaphragm pump	a pump that operates as a flexible wall, collapses and expands.
Downwind	on the opposite side from the direction of the blowing wind.
Drag	resistance caused by friction in the direction opposite to that of the motion of the center of gravity of a moving body in a fluid.
Drag-type systems	devices that are actuated by aerodynamic drag in a wind stream (e.g. Savonius rotor).
Eccentric wheel	a wheel in which the axle is not at the center point, but slightly off center.
Feathering	a system in which the blades on a windmill are designed to change their angle to the wind as the windspeed changes.
Flange	a projecting rim of a mechanical part.
Flywheel	a rotating element attached to the shaft of a machine for the maintenance of uniform angular velocity and revolutions per minute.
Furling	rolling up of the sails.

Galvanize	to deposit zinc on the surface of metal for protecting the metal from rust.
Gusset	a triangular metal brace (support) for reinforcing a corner or angle.
Gust	a sudden, brief increase in the speed of the wind.
Guy wire	a wire or rope securing the windmill blades on the tower poles for keeping them in position.
Helical	pertaining to a cylindrical spiral.
Hub	the cylindrical central part of a wheel, propeller or fan.
Hub extension	a piece of pipe that sticks out from the front of the hub and provides a place to attach guy wires to strengthen the blades or sail wings.
Kinetic energy	the energy which a body possesses by virtue of its motion.
Lathe	a machine for shaping a work-piece by gripping it in a holding device and rotating it under power against a suitable cutting tool for turning, boring, facing or threading.
Lattice tower	a tower made of a network of crisscrossed strips of metal or wood.
Lift	the vertical height travelled by a cage in a shaft.
Lift-type devices	systems that employ air-foils or other devices to provide aerodynamic lift in a wind stream.
Odometer	an instrument attached to a wheel for measuring distance travelled.
Peg	a small pointed or tapered piece, often cylindrical, used to pin down or fasten parts.

Positive displacement pump	a pump in which a measured quantity of liquid is entrapped in a space, its pressure raised, and then it is delivered e.g. a reciprocating piston cylinder or rotary vane, gear or lobe mechanism.
Power Coefficient (C_p)	the ratio between the power extracted by the windmill and the power available in the wind. Theoretically the maximum value of C_p is 0.593 and is known as the Betz limit.
Pump stroke	the distance the pump piston travels between its highest and lowest points.
Rated windspeed	the windspeed as the allowable maximum for continuous reliable performance of the windmill.
Reciprocating pump	a pump in which motion and pressure are applied to the fluid by a piston moving up and down in a cylinder.
Rigging	collectively all the ropes and chords employed to support the mast of the windmill and extend the sails.
Rivetting	fastening a bolt by hammering the end.
Rocker arm	a support mechanism which turns on a shaft at one end and moves up and down at the other end.
Rotor	the main component of the windmill which intercepts the wind and converts the kinetic energy of the wind to mechanical energy available as shaft power.
Solidity Ratio	ratio of the blade surface area to the area. swept by the blade. Increased solidity lowers the tip speed ratio.
Spar	a long, round stick of steel or wood, often tapered at one or both ends.
Spoke	a bar or rod radiating from the center of a wheel.

Static head	the vertical height from the surface of the water to the outlet of the discharge pipe.
Straddled	to part the tower legs wide.
Swash-plate	a disk set obliquely on a revolving axis.
Swivel	a part that oscillates freely on a headed bolt or pin.
Tail	a flat vane actually attached to the extension of the main shaft, its plane being normally to the wind. A change in wind direction is intercepted by the tail which turns the rotor around to face the wind.
Tip-speed ratio	ratio of the velocity at the tip of the blade to the velocity of the wind. Windmills with low tip speed ratio (1-3) have a high starting torque, and are ideally suited for water pumping applications.
Torque	the force that acts to produce rotation, a twisting force.
Tower	the main supporting structure for the windmill. It is usually made of wood or steel and braced suitably to withstand the various stresses, to which it is subjected.
Trunnion	a pin or pivot usually mounted on bearings for rotating or tilting something.
Turntable	a device to allow the rotor to move around and orient itself to the wind.
Upwind	on the same side as the direction from which the wind is blowing (in the path of the oncoming wind-stream).
Welding	joining two metals by applying heat to melt and fuse them with or without filler metal.

APPENDIX II.

CONVERSION TABLES

The following tables may be used for conversion from British to metric units and vice-versa.

Length :

1 mm = .039 inch (.003 foot)	1 inch = 2.54 cm (25.4 mm)
1 cm = .39 inch (.033 foot)	1 foot = 30.5 cm (.305 meter)
1 meter = 39.4 inches (3.28 feet)	1 mile = 1.60 kilometer
1 kilometer = 0.62 miles	

Volume :

1 litre = .264 U.S. gallon	1 U.S. gallon = 3.78 litres

1 British Imperial Gallon = 1.2 U.S. Gallon

Weight :

1 kilogram = 2.2 pounds	1 pound = 0.45 kilogram

Energy :

100 watts = .134 horsepower	1 horsepower = 746 watts (.746 Kw)

Speed :

1 mile per hour (mph) = 0.45 meters/sec.	1 meter/sec = 2.24 miles per hour (mph)

Conversion Table

ft	m	inch	mm	imp galls/day	m3/h	l/s	MPH	m/s	lbs	kg
6	1.83	1½	38.1	1000	0.19	0.05	5	2.2	5	2.27
8	2.44	1 3/4	44.5	2000	0.38	0.11	6	2.7	10	4.54
10	3.05	2	50.8	3000	0.57	0.16	7	3.1	20	9.07
12	3.66	2 1/4	57.2	4000	0.76	0.21	8	3.6	25	11.34
14	4.27	2½	63.5	5000	0.95	0.26	9	4.0	30	13.61
16	4.88	2 3/4	69.9	6000	1.14	0.32	10	4.5	40	18.14
18	5.49	3	76.2	7000	1.33	0.37	12	5.4	50	22.68
20	6.10	3 1/4	82.6	8000	1.52	0.42	14	6.3	75	34.02
22	6.71	3½	88.9	9000	1.70	0.47	16	7.2	100	45.36
24	7.32	4	101.6	10000	1.89	0.53	18	8.0	150	68.04
25	7.62	4 1/4	108.0	20000	3.79	1.05	20	8.9	200	90.72
30	9.14	4½	114.3	40000	7.58	2.10	22	9.8	250	113.4
40	12.19	5	127.0	60000	11.37	3.16	25	11.2	300	136
50	15.24	6	152.4	80000	15.15	4.21	30	13.4	400	181
		7	177.8	100000	18.94	5.26	40	17.9	500	226
		8	203.2	200000	37.88	10.52	50	22.4	750	340
		9	228.6				60	26.8	1000	453
		10	254.0				80	35.8		
							100	44.7		

From <u>SWD 79-1 Catalogue of Windmachines</u>. Sept. 1979. p. 36.

APPENDIX III.

IMPORTANT FORMULAE

1. Power from the wind

Power in the wind, $P = \frac{1}{2} mV^2$

where m = mass rate of air available to the windmill
V = velocity of the air

If A is the area intercepted by the wind with the rotor and the density of air, then

$$P = \frac{1}{2} \rho AV.V^2 = \frac{1}{2} \rho AV^3 = CAV^3$$

where C is a constant depending on the units choosen for ρ, A and V.

$A = \frac{\pi D^2}{4}$ where D is the wind rotor diameter

The actual power extracted from the wind by the rotor is given by

$P = C\ CAV^3$ where C_p = power coefficient

2. Power at the pump

If mechanical transmission losses are accounted for, the power available at the pump is given by

$$P = \eta_m C_p CAV^3$$

where η_m is the efficiency of mechanical power transmission.

3. Pump horsepower

1. The metric horsepower of the pump required to lift the water is given by

$$P = 1.1 \times \frac{WQH}{75\eta_{vp}}$$

where W = sp weight of water in kgf/m^3
Q = discharge rate of water in m^3/sec
H = head of water in metres
η_{vp} = volumetric efficiency of the pump

The factor 1.1 takes into account the frictional losses at the pump.

2. Another formula that can be given for water horsepower is

$$P\ (\text{watts}) = QHG$$

where Q = discharge in litres/sec
H = total head in metres
G = 9.81 m/sec^2

The hydraulic power above i in Mechanical Watts. For approximate estimations the following formula can be used

$$P = 10\ QH\ \text{watts.}$$